Study of Corals and Some Associates in the Marine National Park and Sanctuary – Jamnagar

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by

PARASHARYA DISHANT PIYUSHKUMAR

Department of Zoology
Faculty of Science,
The Maharaja Sayajirao University of Baroda
Vadodara - 390 002, Gujarat
JUNE 2012

Department of Zoology
Faculty of Science
The Maharaja Sayajirao University of Baroda
Vadodara-390002, Gujarat, INDIA

CERTIFICATE

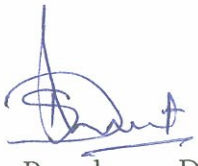
This is to certify that the thesis entitled "Study of corals and some associates in Marine National Park and Sanctuary – Jamnagar", submitted by Shri Parasharya Dishant Piyushkumar for the award of the degree of Doctor of Philosophy has been carried out under my guidance in the Department of Zoology, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat. The matter presented in this thesis incorporates the findings of independent research work carried out by the researcher himself. The matter contained in this thesis has not been submitted elsewhere for the award of any other degree.

Dr. Geeta Padate
Research Guide
Associate Professor
Department of Zoology
Faculty of Science
The M.S. University, Baroda
Vadodara – 390 002, Gujarat

18 June 2012

DECLARATION

I hereby declare that the entire work embodied in this thesis has been carried out by me under the supervision and guidance of Dr. Geeta Padate and to the best of my knowledge no part of this thesis has been submitted for any Degree or Diploma to this University or any other University or Institutes in India and abroad.



Parasharya Dishant Piyushkumar

Department of Zoology
Faculty of Science
The Maharaja Sayajirao University of Baroda
Vadodara – 390 002, Gujarat

THIS WORK IS DEDICATED TO

THE MOST BEAUTIFUL GIRL OF

MY LIFE,

MY WIFE, JANKI

AND SWEETEST BOY

MY SON, TAKSH

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ABBREVIATIONS

CMFRI = Central Marine Fisheries Research Institute

DO = Dissolved Oxygen

DOD & SAC = Department of Ocean Development and Space Application Centre

GEER = Gujarat Ecological Education and Research Foundation

GES = Gujarat Ecology Society

GoK = Gulf of Kachchh

GSECL = Gujarat State Electricity Corporation Limited

GSFC = Gujarat State Fertiliser Corporation

IOCL = Indian Oil Corporation Limited

MNP & S = Marine National Park and Sanctuary

NIO = National Institute of Oceanography

NTU = Nephelometric Turbidity Unit

TCL = Tata Chemicals Limited

ZSI = Zoological Survey of India

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1. INTRODUCTION

CHAPTER 1
INTRODUCTION

1.1 INTRODUCTION

The word ‘coral’ is derived from the ancient Greek word ‘korallion’, which refers to the precious red coral of the Mediterranean, known to us today as *Corallum rubrum* (Williams, 1986). Taxonomically, corals represent a diverse group belonging to the phylum Cnidaria that also includes the invertebrates such as sea anemones, hydroids, jelly fishes, *etc*. All these animals are radially symmetrical. They usually have a crown of tentacles around the mouth and they lack head.

Corals are marine, mostly colonial, polypoid cnidarians that look like miniatures of sea anemones and live in the skeleton, secreted by their own tissues. A coral polyp can be as small as the head of a pin (*Montipora*) to as large as a foot (*Fungia*) in diameter. Despite being so small, they have an amazing impact over the marine ecosystem. Notwithstanding their size, these species have fascinating influence over space and time. Their far-reaching impact over the eco-system can be appreciated from the fact that these tiny tissues have created gigantic limestone structures, which may be as long as 2000 kms (Great Barrier Reef) along the seashores.

Coral reefs form tropical to subtropical marine ecosystems which embrace diverse groups of marine organisms. The resemble ridges or mounds, and have been formed over millennia as a result of the deposition of calcium carbonate by several carbonate secreting organisms, predominantly corals. The reef may have low or high abundance of live corals

but it supports great diversity of marine fauna and flora, which are interconnected to build reef ecosystem.

Scleractinian corals evolved during the Mesozoic era, 245 million years ago, and diversified into the conspicuous reef builders. Their skeleton is composed of calcium carbonate mineral known as Aragonite. The coral reefs luxuriated until a phenomenal demise towards the end of the era around 65 million years ago when many coral families disappeared. With the beginning of the tertiary period of the Cenozoic era (65 to 2 Ma) various reef builders which appeared similar to today's coral species started existing in the marine environment.

1.2 REEF FORMATION

The formation of a coral reef has always been a controversy among various scientists and it is still a matter of dispute. Till now, three main hypotheses have been advanced which are associated with the ideas of subsidence, submarine platform and variation in the sea level.

Subsidence Hypothesis: In 1842, Darwin proposed the subsidence theory. According to this theory, the fringing, barrier and atoll reefs were formed as successive stages in coral growth around slowly subsiding areas; the slowness with which the sinking took place enabled coral building to keep pace with the subsidence. The growth of the reef is rapid towards the seaward side while very towards near the shore. Due to this, the outer part of the reef is able to keep a balance with the subsidence and the inner part, submerged by sea water gives rise to the lagoon between the land and the reef. As the subsidence continues simultaneously, the depth and width of the lagoon in the inner part of the reef also increases resulting into the formation of a barrier reef. When the reef develops around the

island, the island subsides slowly giving rise to a lagoon. The reef encloses the lagoon forming atolls (Billings, 1975).

Submarine Platform Hypothesis: In 1880, Sir John Murray, an Oceanographer, had proposed the submarine platform theory which is also known as non subsidence theory. According to this theory, as the fringing reef grows towards the seaward side it undergoes wave erosion that produces the fragments which gets accumulated in front of the seaward side of the fringing reef. Further these fragments get cemented into the solid bank and as a substratum for the further growth of the reef. During this process, at the seaward side of the reef, the animals occurring in the inner side of the reef die due to lack of sufficient food and oxygenated water. These dead animal of the inner side get dissolved in sea water resulting into the formation of deeper lagoon and hence a barrier reef is generated. But in case of atolls, reefs were built on subsurface structures which were probably raised to a critical depth at which corals lived, thus allowing reef- building to take place. According to this theory the necessary height for coral growth- about 68 mts was achieved either by marine abrasion of volcanic islands or by the building up of submarine banks by volcanic activity or by submarine plateaus accumulating pelagic deposits. The coral colonies on such submarine plateaus grow both upwards and outwards. The outer side of the reef grows more freely and reaches the surface first forming an atoll enclosing a lagoon. According to this hypothesis the live corals exist in the seaward side whereas towards the inner side of the lagoon only the dead corals occur (Billings, 1975).

Glacial-Control Theory: R.A. Daly discovered the traces of glaciation on the sides of “Mounakea” in the Hawaii Islands of the Pacific oceans. Such evidences encouraged him to propose the glacial-control theory. According to this theory, during the Pleistocene Ice Age, all the corals were destroyed, since during that period the sea level was lowered as a result of volumes of water becoming locked up in the ice sheets. When the sea surface was

at its lowest, some 68 or 80 m below the present level, oceanic islands gradually had their summits planed off by wave action. Due to such wave action, the pre glacial dead coral reefs were eroded away. Then, with the rise in temperature, the ice sheets melted and the sea level rose simultaneously the water became warmer and the corals began to recolonize over the platform formed by the dead coral colonies with upward development of the coral reefs keeping a balance with the rising sea level.

Corals produce Calcium Carbonate ($CaCO_3$) through the process of calcification. Coral reef calcification is predicted to decrease by 20– 60% by 2100, relative to preindustrial levels (Kleypas *et al.* 1999, Müller *et al.* 2004), due to increases in CO_2 levels in the surface ocean in response to rise in atmospheric CO_2. Such decrease in calcification would cause loss of reefs because construction rates are predicted to fall below natural destruction rates.

1.3 ECOLOGICAL IMPORTANCE OF CORAL REEF

Coral reefs protect shoreline

Coral reef plays a crucial role in protecting the shoreline. It acts as a physical barrier against the tidal course and helps in protecting coastal erosion, flooding and loss of infrastructure. Hence, it indirectly reduces the cost of huge destruction during extreme weather conditions.

Resource provider to the marine flora and fauna

More than 750 species of organisms can be found on a single coral reef which includes algae, sponges, marine worms, echinoderms, molluscs, crustaceans and fishes (Venkatraman *et al*. 2003). Coral reefs support a complex and interdependent community of photosynthesizing organisms and animals. The crevices and boulders formed within reefs by constant beating of the waves provide shelter to various species.

Act as Primary producer

Corals exhibit a symbiotic relationship with algae that thrive inside the polyp cells. The algae (zoonxanthellae) produce their own food through photosynthesis and supply upto 95% of the food to the coral polyp for their growth (Venkatraman *et al.* 2003). Because of the immense diversity of coral reefs, there is a great deal of exchange of nutrients with high primary production. The primary productivity of coral reef is estimated at 5-10 g C/m^2/day which is derived mainly from algae (Sorokin, 1995).

Source of livelihood

Coral reefs are economically significant and support human life and livelihoods. Globally, around 500 million people depend directly or indirectly on the reef ecosystem for different resources. About 30 million of the poorest human population worldwide depend exclusively on reefs for their food (Wilkinson, 2008). Many coral species and species associated with coral reefs possess significant medicinal value. Some hard corals are utilized in bone grafts (Demers *et al.* 2002).

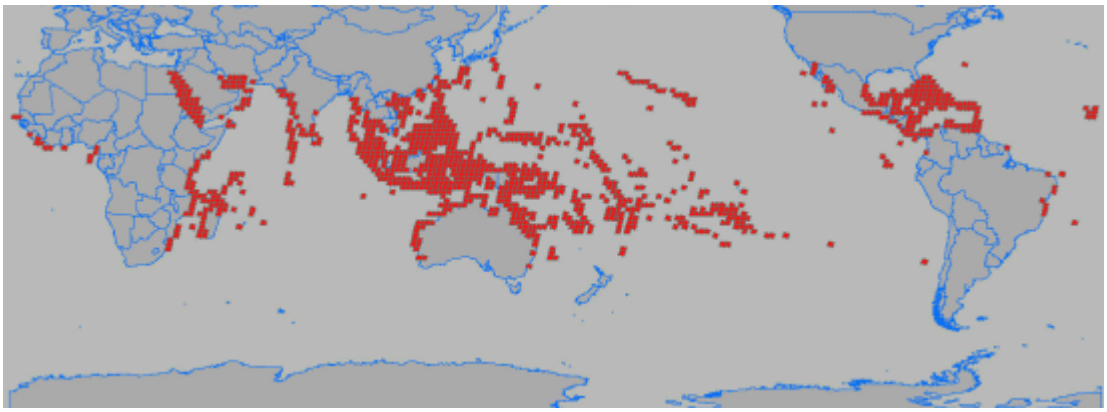
1.4 DISTRIBUTION OF CORALS

CORALS OF THE WORLD

Coral reefs of the world cover an estimated area of 2,84,300 km^2 (Venkatraman, *et al*., 2003) which is less than 0.2% of the global ocean area and about 15% of the shallow sea areas within 0-30 mts depth (Lalli and Parsons, 1997). Around 54% of the coral reefs lie in the Asiatic Mediterranean and the Indian Ocean. Of the remaining, Pacific reefs account for 25%, Caribbean reefs for 9%, Atlantic for 6%, Red Sea reefs 4% and Persian Gulf reefs for 2% (Smith, 1978) (Fig.1.1). A majority of the coral reefs are concentrated on the western sides of the three oceans (Scheer, 1985) however the reason could be geomorphological conditions of these reefs.

The northern most distribution of the coral reefs can be found in the northern Carrebian reefs, the coral reefs of GoK are also considered to be the northern most reef of the Asian continent. Whereas the southernmost distribution of coral reef can be observed in the south of Australia and also in the Southern Africa. The largest reef settlement on the globe is the Great Barrier reef situated in the coral sea off Queensland in the Australian continent. The reef is composed of more than 2900 smaller reefs covering an area of 344400 km2, with more than 400 coral species (Veron 2000). Coral reefs are distributed in a circum tropical band mostly between the latitudes of 20^0 North and 20^0 South. The western Atlantic and the Indo-Pacific are the two main coral reef regions in the world (Wells, 1988). From the biodiversity point of view, the Indo-Pacific reef is roughly ten times more diverse than the western Atlantic reef. For example, there are approximately 60 species of hermatypic corals reported from the coral reefs of the western Atlantic whereas 500-600 species are reported from the Indo-Pacific reefs. Approximately 800-1000 spp. of corals are found all over the world. More than 100 countries are endowed with coral reefs worldwide; most of these are developing countries (Venkatraman *et al*. 2003).

Fig 1.1 Coral reef Distribution in the world (source: coral-reef-info.com)



The species diversity of corals varies at different regions. The maximum coral species are found in South East Asia at a region known as the Coral Triangle (CT) where

76% (605 spp) of the world's coral species have been reported. The Coral Triangle is a geographical term referring to the tropical marine waters of Indonesia, Malaysia, Papua New Guinea, Philippines, Solomon Islands and Timor-Leste. The highest coral diversity resides in the Bird's Head Peninsula of Indonesian Papua, which hosts 574 species (95% of CT total, and 72% of world total), with individual reefs supporting up to 280 species per hectare. Within the Bird's Head Peninsula, reef of Raja Ampat is the World's best coral diversity spot with 553 species (Venkatraman *et al.* 2003).

1.5 CORAL REEFS IN SOUTH ASIA

South Asian coastlines have diverse marine and coastal habitats including coral reefs, mangrove and sea grass. With 19,210 km^2 of reef area, South Asia contributes 6% to the world's coral reef area (Wilkinson, 2008).

Bangladesh, India, Maldives, Pakistan and Sri Lanka are the maritime countries of south Asia bestowed with diverse coral reefs. This ecosystem fulfils the requirement of millions of people for food and livelihood. Coral reefs have a great potential for ecotourism.

I. Bangladesh

Bangladesh is bordered by the Bay of Bengal at its southern boundary. The country has only one coral reef island the St. Martin's island in the Bay of Bengal. Coral reefs of Bangladesh cover about 50 km^2 areas. The live coral cover of this area is generally 5% but it is 10-15% at *Boro Shiler Bandh.* The prevailing coral genera evident here are *Porites*, followed by *Favites, Goniopora, Cyphastrea* and *Goniastrea*. The presence of 37 species of fish and 46 species of algae is indicated in this area. Total- 66 species of sclerectinion corals belonging to 22 genera and 15 families have been reported (Wilkinson, 2008).

The area was declared as an Ecologically Critical Area (ECA) in 1996 under the Bangladesh Environment Conservation Act. The Government of Bangladesh is

implementing Coastal and Wetland Biodiversity Management Project to ensure the conservation of biodiversity in ECAs.

II. Maldives

The Maldives are in the center of the Lacadive-Chagos ridge. The reef area of Maldives covers about 3.14% of the global reef area. It has 1,190 coral islands within an area of 8, 920 km including 23 atolls. The archipelago is surrounded by deep oceanic water and the anthropogenic threats to the reefs are less than other islands of south Asia due to low human population and large distance between atolls. Coral reefs serve as a resource base for major sectors of tourism and fisheries.

A total of 187 species of corals belonging to 33 genera have been recorded from Maldives. Here the coral cover is increasing at all the sites across most atolls as per the survey in 2006 and 2008, but with high variation in reef recovery. The western atolls of Maldives showed a higher coral cover than the eastern atolls. To enhance the conservation efforts for this ecosystem, some international initiatives have been carried out in Maldives; the "Atoll Ecosystem Conservation Project" is one of them (www.mv.undp.org).

III. Pakistan

Recently isolated patches of corals on the hard substratum have been reported along Baluchistan coast in Pakistan. The total reef area is estimated to be less than 50 km^2. Here the high turbidity and sedimentation limits the reef development. The coral communities along the Baluchistan coast have been poorly studied, although surveys around Jiwani and the area near Astola Island have identified 25 coral species and 77 species of reef fish (Wilkinson, 2008).

IV. Sri Lanka

The reef area of Sri Lanka covers about 680 km^2 along the coast. The most extensive coral reefs are offshore in the Gulf of Mannar region. The southwestern coast of

Sri Lanka has fringing coral reefs. Along the eastern coast of the country better development of fringing reefs have been noted, both on the leeward side of the mainlands and on offshore rocks and islands.

The reef types include fringing, barrier and patch reefs. It also includes sandstone/limestone and rocky reef habitats. The coral community represents a total of 183 species belonging to 68 genera.

The coastal area is affected by anthropogenic threats more in comparison to natural threats. The Government of Sri Lanka has declared 5 Sanctuaries since 1973 and 3 National parks since 1969 for the conservation of corals and turtles.

V. India

India, bounded by a coastline on three sides has four major coral reef areas that cover about 5,790 km^2 equal to 2.04% of the global reef area. The four nationally recognized coral reefs include Andaman and Nicobar group of Islands; Lakshadweep Islands; the Gulf of Mannar and the Gulf of Kachchh. Further, satellite imagery shows scattered patches of corals in the intertidal areas and occasionally at subtidal depths down to a few meters along the west coast of India, notably at Ratnagiri, Malwan, Rede port and Vizhingam (Wafar, 1990). The Indian coral reefs show fringing and barrier reefs or atolls and submerged reef platforms. In 1977, a submerged bank with living corals was discovered at Malpe (Mangalore). The bank is about 300 m wide and located about 100 km away from the shore and at the depth of around 35 m (Nair and Quasim, 1978).

India has more than 208 species of hard corals belonging to 60 genera and 15 families. Among 208 species in the reefs of India, the family Acroporidae and Faviidae are dominant.

In 2002, India added a new legislation to protect corals and included corals in Schedule-I of the Wildlife Protection Act 1972 so that corals get maximum protection.

1.6 CORALS OF INDIA

Formation of coral reefs is evidently affected by environmental factors in India. The seasonal monsoons, equatorial calm, tropical cyclone and trade winds are the major factors regulating the reef distribution in the Indian Ocean regions. Tidal ranges are important in reef areas because reefs normally grow up to a certain tide level. Exposure to the atmosphere and desiccation limits the growth of corals, algae and other associated organisms in the reef zones in India (Bakus *et al.*, 1994).

Major coral reefs of India

As discussed earlier the Gulf of Kachchh in Gujarat state, Lakshadweep Islands, the Gulf of Mannar and Palk bay, in Tamil Nadu and Andaman and Nicobar group of Islands are the four major coral reefs of India. With reference to area of reefs of Andaman and Nicobar contribute to 41% of the Indian reefs followed by Lakshdweep (35%), the Gulf of Kachchh (20%) and Gulf of Mannar (4%) (Wilkinson 2008)(Fig 1.2).

India has more than 208 species of hard corals belonging to 60 genera and 15 families. The family Acroporidae has the maximum representation (74 species - 34% of sclerectinian fauna of India). This is followed by the family Faviidae (22 species -11%). On the other hand only one species of the family Trachyphyllidae is reported from Indian reefs (Venkataraman *et al.* 2003).

Alteration in the environmental conditions have given rise to different types of reef formation in different regions. Fringing reefs exist in the Gulf of Mannar, whereas platform and fringing both types of reefs are seen along the Gulf of Kachchh. Patchy reefs are found near Ratnagiri and Malvan coasts in Maharashtra. Atolls can be observed in the Lakshadweep archipelago and fringing and barrier reef surround the Andaman and Nicobar islands (Balasubramanian and Khan, 2001).

The east-west trending Gulf of Kachchh is a shallow water basin which is nearly 60 m wide at the mouth and <20 m of the gulf at head. The Gulf was sub aerially exposed prior to Holocene, because the known sea level was about -65 m prior to 10 Ka BP in this region (Nigam *et al.* 1992). In general, the tides are low on the open Arabian Sea coasts of Kachchh and Saurashtra but due to the funnel shape of the GoK and semi enclosed nature at their heads, the height of the tides increases tremendously from the mouth to the head of the Gulf (Sengupta and Deshmukhe, 2000). Climatically, the Gulf of Kachchh is a semi arid region due to the weak monsoonal rains and high evaporation rate which in turn influence the seawater salinity to increase. Long-term mean rainfall on the surrounding area is 42 cm/y leading to a rainfall volume of 3087 mxm3/y. Thus, the Gulf is an area of negative water balance.

Fig: 1.2: Major coral reefs of India

(Sorce: Balasubramanian and Khan, 2001)

Industrial and other developments along the gulf have accelerated in recent years with the establishment of two oil refineries. In addition, the ports at Okha, Kandla, Navlakhi, Mundra and Jakhau handling a variety of cargo are responsible for considerable ship traffic in the Gulf. Seventy per cent of India's total crude import is expected to take place through the Gulf of Kachchh. Other major industrial developments around the gulf include a soda ash industry at Mithapur, a cement plant, a thermal power plant and a fertilizer factory at Sikka and a cement complex at Mundra. Many of these industries make use of the gulf either directly or indirectly, that may be to draw seawater for cooling, to release wastewater including the return coolant or export/import of materials. Several medium and small-scale industries and saltpans also make use of the Gulf water in a variety of ways. The biggest victims of unchecked industrialization and the resultant pollution and habitat degradation in the area are the coral communities.

The first reports on corals of this area were published by Hornell (1909a,b), Patel (1976 and 1978), Pillai *et al.* (1979), Scheer (1984) and Wafar (1986). These authors have reported the distribution and diversity of coral fauna with main emphasis on the taxonomy of corals of this region. However, the study on density and influence of various physicochemical factors of water on the corals of this region are lacking. Hence, a study was planned to evaluate the status of corals on some identified islands in the southern Gulf of Kachchh, which is also India's first Marine National Park and Sanctuary.

In the post independence time, Gideon *et al.* (1957) described the occurrence of scleractinian corals from the Gulf of Kachchh. Pillai *et al.* (1979) gave a report on their preliminary survey at various locations such as Paga and Boria in the western gulf and Pirotan in the eastern GoK. In this they mainly described the coral formations and its

diversity. The duo of C.S.G. Pillai and M. I. Patel contributed maximum in the reef research of the Gulf of Kachchh. The most comprehensive publication (Pillai and Patel, 1988) described 37 species of hard corals from 16 different reefs of the southern Gulf of Kachchh. Further, Patel (1978, 1985) described the impact of mining on the reefs of the Gulf of Kachchh while, Patel (1985) also described the patchy coral reefs of the gulf. Patel (1978) also gave an account of the coral diversity at Poshitra point, in which he studied 16 reefs present in the Poshitra bay. Recently the El Nino oscillations in the year 1998 drew attention of many researchers towards the global phenomenon of coral bleaching. Arthur (2000) described the bleaching event in all the major reefs of India including the Gulf of Kachchh, and concluded that the reefs of the GoK are more resistant to the environmental fluctuations.

1.7 THREATS TO CORALS

Globally coral reefs are exposed to different types of threats which are natural or anthropogenic. Some natural threats might have been enhanced by the anthropogenic activities.

Natural threats

Storms: Coral reefs can be harmed by hurricanes, tsunamis and cyclones. In most of the cases branching corals are more susceptible to storms. But storms are a natural climatic phenomenon hence to some extent these corals are expected to be adaptable to such unpredictable conditions.

Temperature variations: A particular temperature range can only favour the growth and recruitment of corals. Even a slight variation in temperature can be disastrous to the corals. Increased temperature from a particular range can compel the coral polyps to

expel their zoonxanthellae-the algae that enhance the coral growth. Such expulsion of the zoonxanthellae leads to coral bleaching.

Anthropogenic threats

Pollution: Coral reefs can be damaged due to various pollutants especially the agricultural runoff that mainly comprises of herbicides, pesticides and various nitrogenous and phosphorous fertilizers. These pollutants enhance algal growth resulting into algal bloom, which is much faster and is capable of outcompeting the corals. In some cases human sewage adds compounds that act as nutrients for some micro organism and hence enhance the growth of the micro organisms that causes Eutrophication. Some times the bacteria added by the sewage are suspected to be the cause of coral diseases. Chemical pollutants such as oil spills are also very harmful to the coral reefs especially during the spawning period as the oil can kill the sperms and the eggs. Solid pollutants such as plastics and discarded fishing nets can also cause harm to the coral reefs.

Sedimentation: The increased urbanization and deforestation has accelerated the rate of sedimentation. A thin layer of sediments over the coral reef can be cleaned by the coral itself but such a cleaning process by the corals cannot overcome the high rate of sedimentation. This can lead to a deposition of thick sediment cover on the coral reefs. Such high sediment load reduces light penetration and this results in reduced photosynthetic activity of zooxanthellae. The increased sedimentation rate has resulted due to removal of some important coastal flora such as mangroves and sea grasses.

Destructive fishing: A coral reef is one of the most diverse ecosystems with various types of biota that includes marine flora and fauna. Among fauna, fishes are the most important group thriving in the reef ecosystem. Reefs provide food and shelter to these fishes. Sometimes, fisherman practice fishing in these reef areas by using explosives or

chemicals to capture fishes. Such blasting activity destroys the corals and flatten the reef structures whereas the chemicals kill the coral polyp and other small fishes. Hence, such destructive fishing practices harm the coral reefs.

Global Change: Global warming has a harmful effect on the earth's atmosphere which in turn has also affected the marine climate. Along with the terrestrial ecosystems, marine ecosystems, including coral reef ecosystem, are also getting affected. Global increase in the temperature has been caused mainly by the increased concentration of CO_2 in the atmosphere. The CO_2 concentration of the ocean is 50 times more than the atmospheric CO_2 concentration (www.waterencyclopedia.com). The increased CO_2 concentration causes acidification reducing the pH value of the marine water. This may result in the dissolution of the coral skeleton and affect the huge reefs.

Human Contact: Human contact has also proven to be harmful to the coral reefs. Especially divers, trying to touch the corals may feel thrilled, but can damage homes of various tiny organisms. Even boats and dropped anchors can cause severe damage to these fragile ecosystems. At places where the coral reefs get partially exposed during low tides, walking can also damage live corals and other coral reef biota.

To identify the current status of any reef three major components are required to be assessed (English *et al.* 1994).

(a) The Coral community

(b) Associated faunal / floral Community

(c) Surrounding environs

Nevertheless, no significant current publications are available for the status of coral reefs of Gulf of Kachchh, with reference to various hard coral species with their distribution, live coral cover, the water quality, and the status of any associated fauna. The opisthobranch fauna of the GoK is least explored group amongst other associates. They act

as indicators of reef health. With this background a study of coral reefs of Gulf of Kachchh was planned with the objectives defined as follows:

- To know the species composition of corals in identified reef as well as over all species composition in the Marine National Park and Sanctuary - Gulf of Kachchh.
- To know the other associated fauna of the reef
- To assess the identified parameters of GoK water with reference to live coral cover.

2. REVIEW OF LITERATURE

CHAPTER 2
REVIEW OF LITERATURE

2.1 History of Reef Research

Throughout human history, the word ‘coral’ was used for a wide variety of invertebrate marine organism. The Greek word “cheirallion”, i.e. ‘what becomes hard in hand’ was used for precious red coral *i.e. Corallium rubrum* (Best, 1999).

Darwin’s monograph (1842) is considered to be the first detailed documentation of the basic coral reef ecology. In this monograph titled “The Structure and Distribution of Coral reefs” he explained in detail the origin of reef evolution. With the theory of subsidence in his monograph, he also gave an account of environmental factors which favoured the reef growth, and emphasized on various depth at which coral colonies may grow. In 1872, James Dana one of the chief taxonomists of the scleractinian fauna, described various coral fauna in his book “Corals and Coral Islands.” Though being a geologist he explained the origin and the factors causing the various distribution patterns in the world. In addition like a biologist, he also described various polyp forms of corals, as well as how they differ from other Cnidarians. Since last four decades the awareness in the field of coastal and marine biodiversity research has been found to be comprehensive. Many scientists have described the distribution as well as the physiological aspects of corals and coral reefs.

Corals are found throughout the world from the freezing Polar Regions to the equatorial regions and from the deepest trenches to the intertidal zones of the ocean

(Williams, 1986). However the reef building corals are limited in geographical distribution *i.e.* their presence is detected more prominently in the tropical regions of the world (Goreau. *et al.* 1979). Naim *et al.* (2000) referred corals as two layered invertebrates that live in groups and are related to jellyfish and sea anemones having polyp and/or medusa form. In some corals the polyp -a single individual- extracts calcium carbonate from the sea and secretes it as a cup of calcium carbonate from the bottom half of its body. Veron (2000) explained that when the calcium carbonate cups of many billions of individuals fuse together, the structure is referred to as a reef. Reefs are the massive limestone structures built up through the constructional cementing and depositional processes by the corals and all other calcium secreting organisms including calcareous algae (Balasubramanian and Khan, 2001). The coral reefs are the richest and most complicated marine ecosystem on earth (Wilkinson, 2008) and are believed to be the oasis of the oceans because they are small areas but with a very high productivity occurring within the vast ocean (Venkataraman *et al.*, 2007).

Coral reefs represent an important resource to coastal nations, providing source of food, building material and revenue through tourism and the aquarium trade (Naim *et al.* 2000; Spalding *et al.* 2001). They also provide natural coastal defenses and are regions of high biodiversity (Bellwood and Hughes, 2001). Over the past three decades, decline of coral reef abundance and diversity have been observed globally due to anthropogenic and natural causes (Hughes, 1994; Ginsburg, 1996;McClanahan and Muthiga,1998; Morelock *et al*.2001). Increased coastal development and agricultural runoff leading to a higher sediment accumulation and suspension, together with discharge of sewage and industrial waste into the ocean have been found as major cause for the decline of the present coral reef (Hughes, 1994; Hughes and Connell, 1999, Morelock 2001).

Corals and coral reefs all over the tropical waters are under stress due to various anthropogenic and natural interventions. The interference of these factors on Indian reefs have been reported by several workers (Pillai, 1996; Venkataraman *et al.* 2003; Wilkinson, 2000; Patterson *et al.* 2007). The major natural causes for the destruction of corals include siltation, cyclone, local tectonic upheavals, tsunami, pests and predators and EI Nino. During 1998 a notable rise in surface water temperature was observed and large scale mortality of corals was reported as a result of 1997/98 El Nino southern oscillation. Venkateraman (2000) reports that this has affected reefs in Gulf of Mannar and many species of corals were bleached. However, subsequent study by Patterson (2007) shows that the southern part of Gulf of Manner has densely populated reefs and there is no sign of impact of El Nino event. From the value of this marine benthic, tropical community, need for conservation of coral reefs is evident. Though reefs were present and mankind utilized their resources from time immemorial a greater awareness for the conservation and protection emerged only in later half of the last century, due to over exploitation and pollution of natural resources. Early workers in the 19th century did not argue much for protection to reefs, as reefs survived in healthy conditions. But indiscriminate exploitation and unhealthy interference on reefs by man threatened these ecosystem and ecologists and naturalists started pointing out the necessity for reef conservation. India had the privilege to host the first International symposium on corals under the auspices of the Marine Biological association of India in January 1969 wherein reef scientists from 11 countries participated. An international committee for the conduct of further symposia in every 4 years was also constituted. And till date 10 symposia have been conducted in various tropical countries. However, involvement in the series of meetings later was virtually nill from India. Total 11 proceedings are published. As on today the status report of coral reefs

"Status of Coral Reefs of the World" is being published at an interval of four year by Global Coral Reef Monitoring Network (GCRMN).

2.2 The Indian Scenario

The studies on the taxonomy of Indian corals have a history of nearly 160 years by Link (Pillai 2010) from Nicrobar Islands, Parallel to the works of Darwin. Subsequent studies by British scientists on material housed in British Museum of Natural History, London and works of Late Prof. George Matthai and C. S. G. Pillai have elucidated the coral fauna to some extent. This was considered to be the first stage of surveys, which were basically unplanned as they were a part of the Surveys of other coastal ecosystems (Wafar Coral reef surveys in India 1988). Pillai estimated the coral fauna of Gulf of Mannar and Palk Bay (1972;1986), Lakshadweep and Gulf of Kachchh (Pillai and Patel, 1988) and Andamans (Pillai, 1983) west-coast of India i.e. the erstwhile Travancore coast including Kanyakumari coast (Pillai and Jasmine, 1991). For details of references the recent work of George and Sandhya (2007) may be referred along with Pillai (1986). Pillai (1996) published a detailed status report on the corals and coral reefs of India which still remains as the basic document. However subsequently status reports were prepared and published by several authors including Wilkinson (2000), Muley *et al.* (2000) and Patterson *et al.* (2007). Pillai (1996) listed 199 species of corals from Indian waters belonging to 71 genera of which 55 were colonial hermatypes and the rest ahermatypes. The hermatypes comprised 155 species and the rest deep sea or shallow water ahermatypes. Venkataraman *et al.* (2003) lists 208 hermatypes from India. Additional information based on recent works from Marine biosphere in Gulf of Mannar accounts for nearly 8 more species, thus totaling to about 220 species (subject to further taxonomic review) of colonial corals plus nearly 45 species of deep water and shallow water ahermatypes. This accounts for about 265 species of stony corals from Indian waters.

However, Venkataraman *et al.* (2003) states another 111 species of hermatypes from Anadamans by underwater diving which should be added to the list. The species listed by SCUBA diving on more sights, are unreliable since identification of corals *in-situ* underwater with any certainty is difficult (Pillai, 2010). Wells (1973) stated that approximately 700 species of corals occur in the whole of Indo-Pacific region. However, this is also not final. Since several authors, especially the Australian workers have added many more species to the biodiversity of Indo-Pacific corals. If one takes John Wells (1973) estimate of 700 species along with additional information provided by recent workers the total will be about 775 species. This indicates that approximately 35% of the Indo-pacific corals occur in Indian waters. Since Pillai's work on Lakshadweep and Gulf of Kachchhh no intensive survey in those areas has been done especially the deep waters facies. In essence to get a realistic picture of our coral resources we have to do more data collection, increase literature survey settling of the synonymy and the likes. This is to be done by a team of expert scientists, SCUBA divers and technical persons who are dedicated to their assigned task.

2.3 The Gulf of Kachchh

The history of reef based research in Gujarat is almost one century old now. The first comprehensive document on the marine flora and fauna was published under the authorship of James Hornell (1909). Two volumes of his work published for the state of Baroda ruled by the Maharaja SayajiRao Gaekwad II is one of the finest descriptions of the coral reefs of Okhamandal (now known as Poshitra cluster). Hornell also described the reef based chank fishery and other fishery based small scale businesses. He also described some of the important groups of the reef diversity such as hydroids, polyzoans, nudibranchs and poriferans.

In the modern era of coral reef research, Gideon (1957) described the first occurrence of scleractinian corals from the area. Pillai and Rajagopalan (1979) gave a report on their preliminary survey at various locations such as Paga and Boria in the western gulf and Pirotan in the eastern gulf. They mainly described the coral formations and its diversity. The duo of C.S.G. Pillai and M I Patel contributed maximum in the reef research of the Gulf of Kachchh. The most comprehensive publication (Pillai and Patel, 1988) described 37 species of hard corals from 16 different reefs of the southern Gulf of Kachchh. However Patel (1978;1985) described the impact of mining on the reefs of the Gulf of Kachchh. Patel (1985) also described the patchy coral reefs of the Gulf of Kachchh. Earlier Patel (1976;1978) had also given an account of the coral diversity at Poshitra point in which he studied 16 reefs present in the Poshitra bay.

DOD and SAC (1997) gave detailed mapping of the Indian Coral reefs using remote sensing as a tool, dividing them into various reef classes. The report also includes detailed work of the Gulf of Kachchh coral reefs. SAC (2003) also published "Ecomorphological Zonation of the Coral reefs of India", in which few of the coral reefs of the GoK has been included for supervised classification of the habitat. Recently SAC (2010) has published an "Atlas of Coral reefs of India", in which they have classified some of the coral reefs of GoK in various geomorphologically distinct habitat classes.

Amongst other studies a detailed ecological study of the reefs of Gulf of Kachchh was carried out by Naik *et al.* (1991) (Bio-Science department of Saurashtra University) funded by WWF. However the report mainly focused on the avifauna of the area. Where as Kundu (2001) described the intertidal macro fauna of the Narara and Sikka intertidal area.

The El Nino oscillations in the year 1998 drew attention of many researchers towards the global phenomenon of coral bleaching. Arthur (2000) described the bleaching

event in all the major reefs of India including the Gulf of Kachchh, which concluded that the reefs of the GoK to be more resistant to the environmental fluctuations.

Pradhan *et al*. (2004) described the utility of remote sensing for classifying the reefs with reference to their eco-morphological zones. Vethamony *et al.* (1996;2005) described the Physical processes such as current circulation and sediment dispersal with special reference to the coral reefs of the Gulf. Chauhan *et al.* (2000;2006) mainly described the sedimentation and suspended solids in the Gulf of Kachchh.

Deshmukhe *et al*. (2000) gave an overview of the coral reefs of the Gulf of Kachchh, in which they described the diversity of corals at Pirotan, Kalubhar, Boria and Beyt Shankhodar in the southern. Pandey *et al*. (2010) gave the recruitment and growth rates of some corals at six locations in the Gulf of Kachchh.

With reference to the Gulf of Kachchh coral reefs there are no significant publications on the community structure of corals and the coral cover and coral health. Also, there is no significant recent publication on the species composition at major reefs. Hence one of the objectives of the study is to understand the coral community and species composition of GoK in detail.

2.4 Mollusca (The associated fauna)

Molluscs are a dominant component of reef community. The global estimate of molluscan species is around one lakh fifty thousand. A cottage industry in south India exists on molluscan shells. Since the ancient times mollusca is one of the important Phylum and was popular in trade. The cowries were used as currency against any kind of purchase. The number of species of molluscs recorded from various parts of the world varies from 80,000 to 150,000. In India 5070 species have been recorded of which 3500 + are from the marine habitats (ZSI 2004). Andaman and Nicobar regions have a rich diversity of marine Mollusca, which include more than 1000 species (Venkatraman, 2003).

One of the most premier expeditions has taken place in the regions of Andaman and Nicobar by Dampier as early as 1688. Hornell published 3 full papers (JBNHS (vol 48 i, ii, iii) 1948-49) giving a full account of the molluscan biodiversity of Indian sea waters with main focus on the class Gastropoda and Bivalvia. However, in addition to this publication, Hornell (1909) started his expeditions from the Gulf of Kachchh and gave a detailed account of the Chank fishery, diversity of some of the Nudibranchs and also described in detail the potential of oyster bed fishery of the Okhamandal (Currently known as Poshitra cluster). In most of these pre independence research publications the emphasis was mainly given to the shelled Gastropoda. Prismatic, conspicuous, majority of shell-less Gastropoda of coral reefs, the Opisthobranchs, popularly known as sea slugs were highly ignored, though these creatures are highly beneficial in biomedical research.

Indo-Pacific opisthobranchs were studied by Gosliner and Willan (1991), Gosliner (1992;1994a,b), Gosliner and Behrens (1998), Gosliner and Johnson (1999), Jensen (1994), Rudman (1980;1984;1986;1990), Yonow (1984a,b;1986;1988;1989;1990;1991; 1994;1996;2000; 2001; 2008a,b), Yonow and Hayward (1991), Fahey and Gosliner (2003) and Apte (2009). Apte (1998) also published the first ever pictorial / field guide to the marine shells of India, in which he emphasized on shelled gastropods and bivalves. Brunckhorst (1993) reviewed the Phyllidiidae in Indo-Pacific region, which Yonow (1996) reviewed 11 species from the Indian Ocean. More recently Dayrat (2010) reviewed basal *Discodorids* of the world.

The first available report of Opisthobranchiate fauna of India was on the collection of Eliot (Alder and Hancock, 1864). This paper deals with 42 species belonging to 10 families of which, 30 species and 4 genera were newly described. The research on the molluscan / Opisthobranch fauna of India can be divided in to two major phases pre-independence and post-independence. In the first phase the major focus of the research

was taxonomy and distribution (Balfour 1873; Eliot 1906 a & b;1909;Gravely 1910;Rao 1937). However the second phase was mainly the publications on diversity including earlier reports of Opisthobranchs (Burn, 1970; Narayanan, 1967;1968; Rao, 1936; 1961;1962;1973; Rao & Rao, 1980). The most recent publications are on Opisthobranchsare from 3 reefs *i.e.* Andaman and Nicobar (Ramakrishna *et al.* 2010) and on Gulf of Kachchh and Lakshadweep (Apte *et al.* 2010).

Recently the application of the biochemical defense mechanism of Opisthobranchs took attention of scientists working on Biochemistry. The chromosomal studies, bio-active component extraction, metabolites and other applications are also published (Danialdoss 1996;Fontana *et al.*, 2001; Gulavita *et al.*, 1991).

2.5 Molluscan status in the the Gulf of Kachchh

As stated earlier the Molluscan studies in this region dates back by Hornell (1909) in which he described the Chank fishery. The Chank fishery was also described by Patel (1985). Raval *et al.* (2002), as a part of the ecological study of Narara and Manjar reef in the Marine National Park and Sanctuary in the Gulf of Kachchh, also studied the molluscan diversity. Gideon (1957) gave a family wise description of various phyla occurring in the marine waters of the Gulf of Kachchh including Mollusca. The publication was followed by two other detailed taxonomic papers on the molluscan fauna of the Gulf of Kachchh (Menon *et al.*,1961; Kundu, 1965).

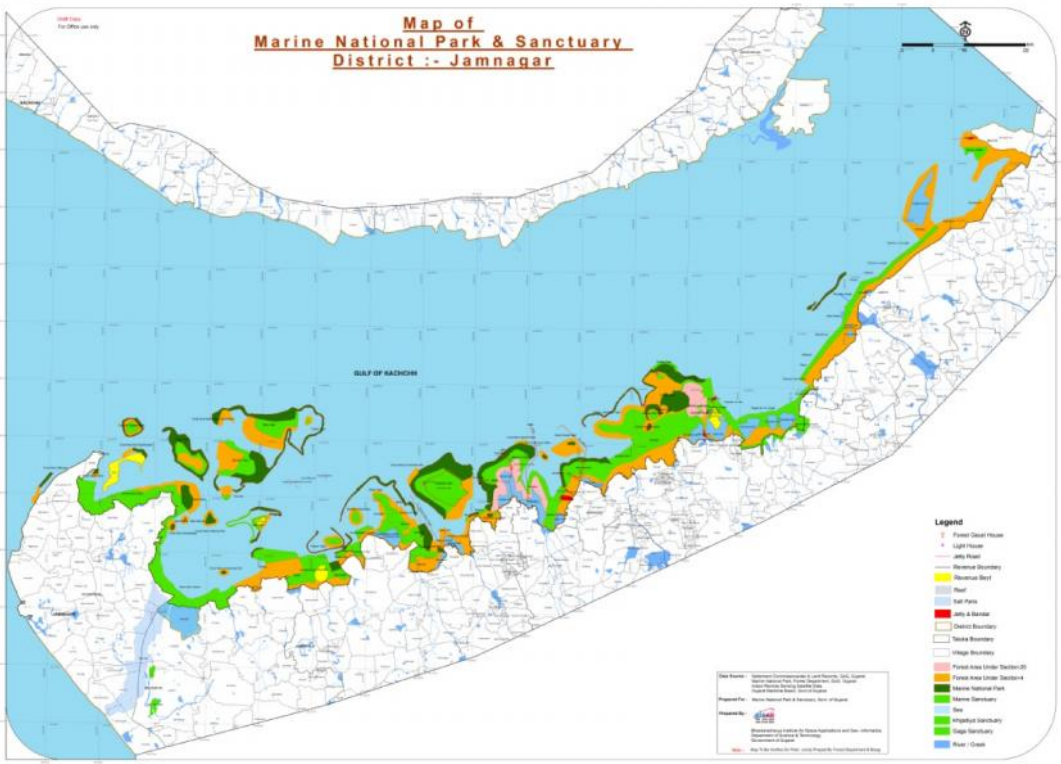
The publications on the opisthobranch fauna of Gulf of Kachchh are limited to a few publications by Burn (1970), Narayanan (1970), Eliot (1909a,b)**,** Gideon *et al.* (1957), Menon *et al.* (1961), Narayanan (1969;1970;1971a,b), Rudman (1980), Deomurari (2006) and Apte *et al.* (2010). The most comprehensive work on the opisthobranchs of the Gulf of Kachchh was that by Narayanan (1969;1970;1971a, b) and Apte *et al.* (2010).

Referring to these publications the information on coral reef associated Opisthobranch fauna is very limited. It is quite likely that some of the Opisthobranchs are indicators of reef health (Apte *et al.* 2009-10 Annual report) and it is important to understand the Opisthobranch diversity of coral reefs in the Gulf of Kachchh.

2.6 MARINE WATER QUALITY

Attention to water quality is having longer history than other oceanographic processes, as the known science of chemistry is also involved in it. However the impact and correlation of the living organisms with its surrounding water quality is less documented. In the last decade, lot of research was carried out to understand the carrying capacity of the marine ecosystems such as coral reefs and mangroves. With industrial development taking place in and off shore, it requires lot of monitoring of sea water.

3. STUDY AREA


Map of
Marine National Park & Sanctuary
District :- Jamnagar
GULF OF KACHCHH
Legend

CHAPTER 3
STUDY AREA

3.1 INTRODUCTION

The western state of India "Gujarat" faces the Arabian Sea. The waters of the Arabian sea wash 1650 km long coast of the state giving it the longest coastline among all the Indian maritime states. About 60% of the coastline comprises the indentations of the two gulfs *viz.* the Gulf of Kachchh and the Gulf of Khambhat (Anon, 1997).

3.2 GULF OF KACHCHH (GoK)

Gulf of Kachchh (The word "Kachchh" is being spelt in many ways, here we adhere to "Kachchh" as indicated by GCRMN and ENVIS publication of CASMB, Balasubramanian and Khan, 2001) is the largest coastal habitat in the West coast of India in the state of Gujarat (20° 15' to 23° 35' N and 60° 05' to 70° 22' E). It is funnel shaped, East – West oriented, seismically active indentation and one of the three macro-tidal regions of India (Chauhan *et al*. 2006). The Gulf of Kachchh, ~125 km long and 75 km wide (the longest along the northwest coast of India), lies between the mainland of Kachchh in the north and the Saurashtra/Kathiawar peninsula in the south and is open to the Arabian Sea in the west (Laju *et al*. 2009). It also passes through semi-arid and arid region of Little Rann and is flanked by coral reefs (Anon, 1997).

3.3 COASTLINE SURROUNDING GULF OF KACHCHH

The total area of the Gulf of Kachchh is around 7350 km^2 (GES, 1997). The coastline surrounding the gulf consists of low-level coastal plains with inundations, deep inlets, a

number of offshore islands, and several small, seasonal river mouths. A cluster of nearly 42 islands are present in the southern gulf near Jamnagar coast. (Plate 2.1) (Pandey *et al.* 2010).

3.4 TIDES AND CURRENTS

The Gulf of Kachchh has one of the highly energetic, macrotidal systems of the north eastern Arabian Sea (Vethamony and Babu, 2010), with mixed semi-diurnal type (Sengupta and Deshmukhe, 2000) tides. Tidal range at the mouth of the Gulf is about 4 meters (Desa *et al.* 2005). In general, the tides are low on the open Arabian Sea coasts of Kachchh and Saurashtra but due to the funnel shape of the GoK and semi enclosed nature at their heads, the height of the tides increases tremendously from the mouth to the head of the GoK (Sengupta and Deshmukhe, 2000). The tidal amplitude in the north of the GoK varies from 3 to 8m while in the south it is 3 to 5m (Sengupta and Deshmukhe, 2000). The associated tidal currents are fairly strong, reaching 4 to 5 knots in the open gulf near the mouth. High tidal range and associated tidal currents are effective geological agents and would have played a significant role in sedimentation and shaping of the floor (ANON, 1997).

3.5 CLIMATE AND SEASONS

Climatically, the Gulf of Kachchh is in semi arid region due to the weak monsoonal rains and high evaporation rate which in turn influences the seawater salinity. Long-term mean rainfall on the surrounding area is 42 cm/y leading to a rainfall volume of 3087 mm^3/y (Nair, 2002). Thus, the Gulf is an area of negative water balance. The region experiences four main seasons namely winter (November, December, January, February), summer (March, April, May), south west monsoon (June, July, August) and post monsoon (September and October). Except in late summer and southwest monsoon, throughout the year the winds in the gulf are light to moderate. Stronger winds are also encountered with the disturbances such as

western depressions and cyclones. This region is severely influenced by the storms occurring in June-July with devastating effects on coastal areas. In the GoK, the air temperature varies from minimum 10°C to > 36°C over the year. The month of January is considered to be the coldest month with night temperatures falling below 10°C and May and June are considered to be the hottest months with mean maximum temperature of 36°C during day and mean minimum of 26°C during night (Nair, 2002). The relative humidity is generally high during monsoon and range from 70 to 80%, whereas, during rest of the year. It ranges between 55 and 70% (Nair, 2002).

3.6 HYDROGRAPHY

The GoK is a relatively shallow basin with the depth extending from ~60 m at mouth to 20 m at neck region (Nair, 2002). The Gulf has been hydrographically surveyed several times due to navigational interests in the southern shoreline. Within the Gulf, though water depths of 25 m exists in broad central portion up to the longitude of 70°E, the actual fairway in the outer Gulf is obstructed by the presence of several shoals. The high tidal influx covers the low-lying areas of about 1500 km^2 comprising a network of creeks and alluvial marshy tidal flats in the interior region (Sengupta and Deshmukhe, 2000). All along the coast, very few rivers drain into the Gulf and they carry only small quantity of freshwater, except during monsoon. A large quantity of sediments from river Indus is prograding the shelf along Kachchh. The prograding sediments of the Indus delta accumulate on the northern shores of the Gulf while the southern shore remains deprived of the sediments because of the existence of a dynamic barrier caused by the high velocity tidal stream flowing through the central channel of the gulf (Sengupta and Deshmukhe, 2000).

3.7 INDUSTRIAL DEVELOPMENT AND ITS IMPACT

Longest coastline of Gujarat is the heartland of Indian industries like petroleum, power and steel. It ranks second in the top industrialized states in India (ANON, 1997). The industries around GoK, consists of cement, chemical dyes and dye intermediates, pharmaceuticals, textiles, pulp and paper, rubber and plastics, dairy products and electronics, natural gas and petrochemicals, salt, *etc*. Industrial and other developments along the Gulf have accelerated in recent years with the establishment of two oil refineries. In addition, the ports at Okha, Kandla, Navlakhi, Mundra and Jakhau handle a variety of cargo and are responsible for considerable ship traffic in the Gulf. Other major industrial developments around the Gulf include a soda ash industry at Mithapur, a cement plant, a thermal power plant and a fertilizer factory at Sikka and a cement complex at Mundra. Many of these industries make use of the Gulf either directly or indirectly to draw seawater for cooling, to release wastewater including the return coolant and export/import of materials. In addition, there are several medium and small-scale industries and saltpans which make use of the Gulf in a variety of ways. Seventy per cent of India's total crude import is expected to take place through the Gulf of Kachchh. In addition, chemicals like soda ash, cement, fertilizer, salt works and thermal power stations are contributing to what adds up to an environmental damage. Because of all these developments, fishing, in particular traditional fishing has been very negatively affected by the environmental pollution, and competition from large fishing vessels. Agriculture, which flourished in small pockets, has been destroyed by the degradation of soil and groundwater (Nair, 2002).

Table 3.1: Salient Features of Gulf of Kachchh (GoK)

Salient Features of GoK	
Latitude and Longitude	20° 15’ to 23° 35’ N and 60° 05’ to 70° 22’ E
Length & Width	~125 km and 75 km
Area	73500 km^2
Depth range	20-60 m
Climate	Semi Arid
Mean rainfall	42 cm/y
Mean depth	30 m
River Runoff	140 mm^3/year
Evaporation	7350 mm^3/year
Water Balance	Negative
Air Temperature	10°C to > 36°C
Humidity	55 and 70%
Volume	220,000 Million m^3
Tides	Mean High Water Spring (MHWS) tide from west to east:-3-7 m (Okha-3.47m; Sikka-5.36m; Navlakhi-7.31m)
Salinity (mouth to neck)	35 to 40 ppt
pH	7-8.5
DO (mg/l)	5-8
BOD (mg/l)	< 3
PO_4 (µmol/l)	0.6-1.6
NO_3(µmol/l)	0.7-6.7
Suspended solids	Decreases from inner to outer gulf
No. of islands	42
Surrounding Geomorphology	
Navlakhi-Dwarka	Highly crenulated coastline with extensive mudflats, offshore islands, rocky platforms, narrow beaches and coral reefs. Substrate: Coralline limestone and deccan trap basalt. Sediment: Sandy, silty and muddy
Kori Creek – Mundra	Extensive mudflats, mangroves, small sluggish seasonal streams, creeks. Substrate: Muddy, alluvial, oft tertiary rocks. Sediment: Muddy

(Source: ANON,1997)

3.8 THE MARINE NATIONAL PARK AND SANCTUARY (MNP&S) - JAMNAGAR

The marine ecosystems are one of the most important and valuable biological, economical and recreational resources in tropical areas around the world. But the marine resources have always been over exploited by humans which have victimized them under various anthropogenic and human induced natural threats. In order to protect and conserve the marine heritage of India, 9 Marine National Parks and 24 Marine Sanctuaries have been declared (Venkatraman *et al.* 2003). The declared MPAs are located in Gujarat, Lakshadweep, Maharashtra, Tamil Nadu, Andaman and Nicobar Islands, Andhra Pradesh, Orissa and West Bengal. The Marine National Park and Sanctuary in the Gulf of Kachchh considered as one unit (Marine Protected Area), is one of them. The intertidal zone of the Northern Saurashtra of the GoK has already been the victim of the human greed for persistent over exploitation even before it was properly explored. In the month of August, 1980 and July, 1982, this region was declared as the Marine Sanctuary and Marine National Park (MNP&S). The Government of India declared 457.92 km^2 area as Sanctuary and 162. 89 km^2 as National Park (Singh,1994). This Marine National Park and sanctuary of the Gulf of Kachchh is fortunate of being the first Marine National Park in the country. The MNP & S is situated in the intertidal zone of the Northern Saurashtra, extending to nearly 150 kms in the Gulf of Kachchh and falls under Jamnagar district. Three categories of area are included within the MNP & S (Table 3.2).

The National Park area covers 37 islands while the sanctuary area covers five islands as well as the inter-tidal zone from Navlakhi to Okha. According to the Notification, the revenue borders of Dwarka (Okha), Kalyanpur, Khambhalia, Lalpur, Jamnagar, Dhrol and

Jodiya talukas of Jamnagar District mark the southern boundary of the Marine Protected Area (MPA).

Since the PAs were constituted under the Wild Life Protection Act (1972), the management of the area is under the jurisdiction of the State Forest Department. The MNP & S supports considerable species diversity. The MNP & S was initially established for the conservation and protection of a rich and diverse ecosystem, particularly the inter-tidal and sub-tidal coral reefs and mangrove habitats of the Gulf. Since 1991, coral reefs and mangroves have additionally been accorded the highest degree of protection under the 1991 Coastal Zone Regulation (CRZ) Notification. Coral reefs and mangroves have great ecological significance as both increase shore stability, offer protection against tidal surges and are the breeding grounds of a host of fishes, crustaceans, algae and other forms of marine life. Indeed, the decline in corals and mangroves is correlated with a general decline in the diversity and quantum of marine life.

Table 3.2: Category wise division of the area at MNP&S (Singh, 2001)

Category	**Marine Sanctuary (sq.km)**	**Marine National Park (sq.km)**
Reserve forest	1.11	10.11
Notified under section 4 of IFA 1927	225.52	122.38
Non forest & territorial water	68.4	29.8
Overlapping area of Park and Sanctuary notified for port act before 1980 for maritime activities		398.4

Selection of Study Locations

Zonation and Selection of the study locations

Gulf of Kachchh is a vast area of 150 km long coastline. To simplify understanding the study area was categorized in three different zones *viz.* Eastern Gulf, Central Gulf and

Western Gulf. From each zone two representative sites were selected based on the background information of the area.

These six locations are as follows (Plates No. 3.2, 3.3 and 3.4)

a) Eastern gulf: (Pirotan to Sikka) **Pirotan island, Goose reef**

b) CentralGulf: (Sikka to Dhani) **Narara coast, Kalubhar island**

c) Western Gulf: (Dhani to Chhandri) **Poshitra coast, Asaba Pir reef**

Out of six locations two reefs are coastal reefs *i.e.* Narara and Poshitra, two reefs are fringed to islands *i.e.* Pirotan and Kalubhar and two are submerged reefs, Asaba Pir and Goose, which opens only during good low tide.

Eastern Gulf (Plate: 3.2)

1. Pirotan Island

Location: 22°35.8'- 22°36.2' N and 69°57.0'- 69°57.6' E

General features: The Island is the most popular tourist place in the MNP. It is one of the attractions for the eco-tourism in the MNP. Every year, nature camps were also conducted on this island for the local students to create awareness and knowledge of marine life.

2. Goose Reef

Location: 22°28.6' to 22°30.6' N and 69°47.0' to 69°50.4' E

General features: Goose reef is not an island but an attractive submerged reef which is having diversified reef invertebrates. It is situating just opposite to Sikka. This reef is oval in shape and represents fair amount of flora and fauna.

Central Gulf (Plate 3.3)

3. Narara Coastal reef

Location: 22°25.8' to 22°28.3' N and 69°42.1' to 69°44.7' E

General features: As a result of encroachment due to human activities, this island has become a part of mainland as there is no distinguished marking of mainland. It is directly accessible by road up to the reef area. It is a popular nature camps site to study marine fauna and flora.

4. Kalubhar Island

Location: 22°24.4'– 22°27.5'N and 69°35.3'– 69°39.4'E.

General features: Kalubhar is located in the central part of the Marine National Park & Sanctuary. It is oval in shape and prominently bifurcated by creeks. It is the largest island in the MPA.

Western Gulf (Plate 3.4)

5. Poshitra Coastal reef

Location: 22°24'02"– 22°24'19"N and 69°12'04"– 69°12'33"E.

General features: It is a coastal area with small embayment at Laku point having very good coral formations spread in about 100 m wide area. Before approaching coral reefs at Poshitra one has to cross a rocky patch covered with knife edged shells of oysters and barnacles. The reef area also contains a good amount of rocky pools which are of very crucial need for coral attachment.

6. Asaba Pir Reef

Location: 22°23’31”– 22°23’50”N and 69°12’27”– 69°13’01”E.

General features: Asaba Pir reef is situated in the western side of Poshitra village. The island has prominent rocky crevices at the edges and flat surfaces on the top. There is no reef area as in case of other islands near Poshitra.

Plate 1: Study Area: Six locations in the Marine National Park and Sanctuary – Jamnagar

Plate 2: Study Sites in the eastern Marine National Park & Sanctuary

Site 1: Pirotan

Site 2: Goose

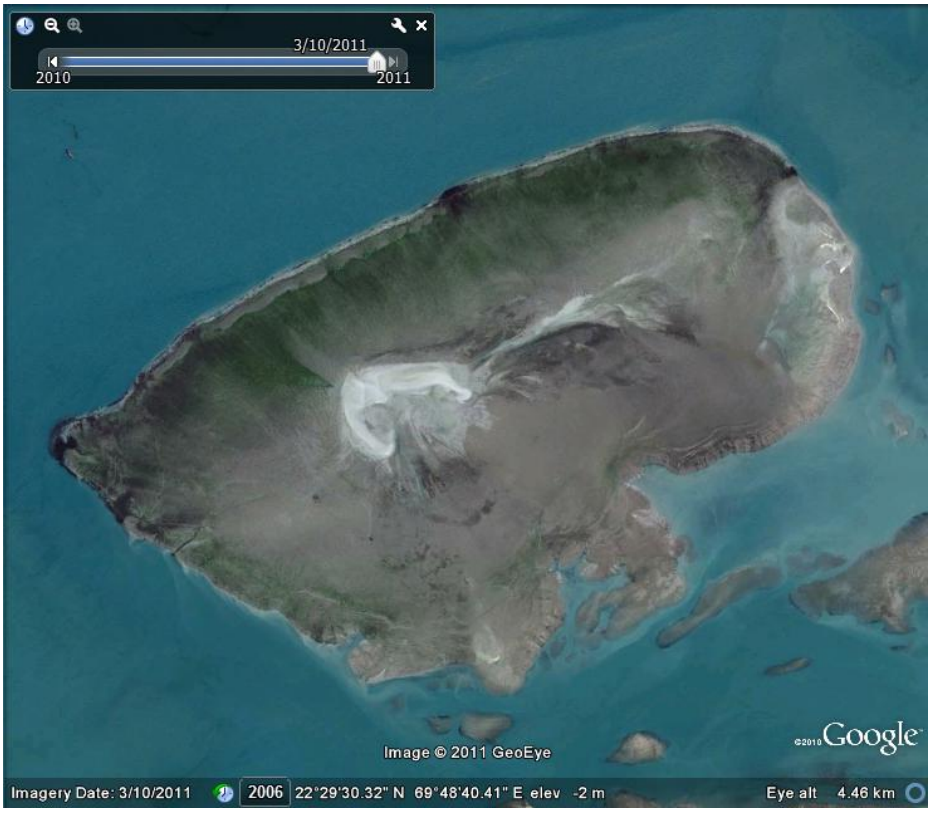


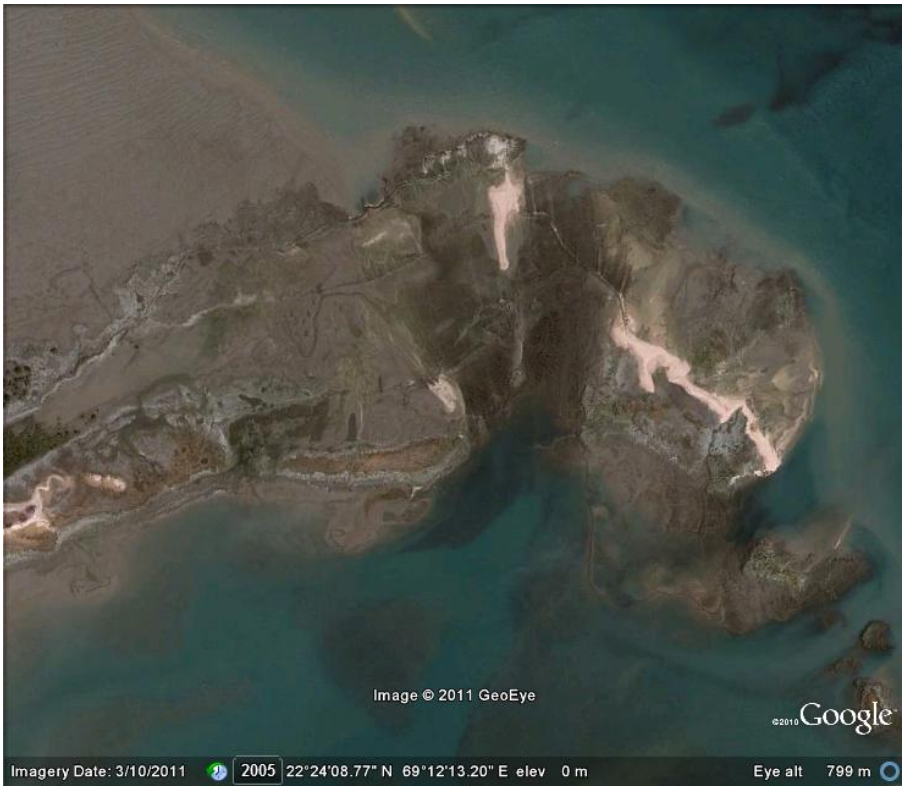
Plate 3: Study Sites in the Central Marine National Park & Sanctuary

Site 3: Narara

Site 4: Kalubhar

Plate 4: Study Sites in the Western Marine National Park & Sanctuary

Site 5: Poshitra



Site 6: Asaba Pir

4. METHODOLOGY

CHAPTER 4
MATERIALS AND METHODS

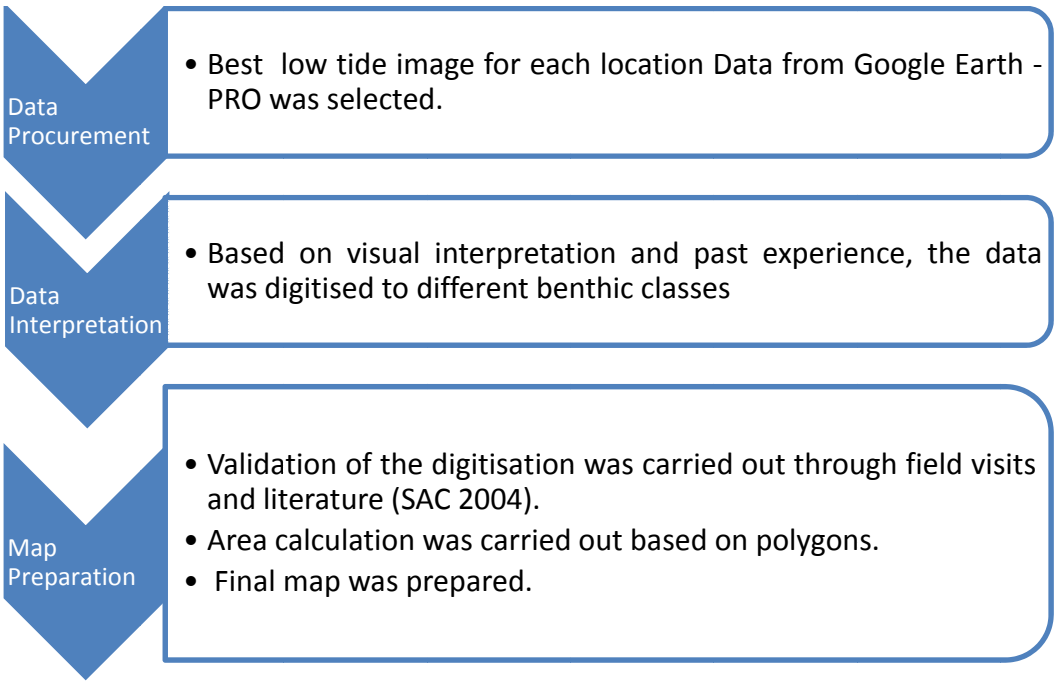
The methodology was divided in three parts

1. **PRE-SAMPLING** (SAC 2004)

Before initiating the sampling, it was required to identify the area where the sampling can be done. For this following steps were taken on the classified Google Earth image.

Preparation of Habitat maps

The methodology adapted for preparing habitat maps for the six study locations was based on google earth pro image and SAC (2004), with some modifications according to the functioning of the Google Earth software as follows:



On the basis of this, total 13 different benthic classes were identified. These are (Table 4.1) as follows

Table 4.1: Benthic Classes of six study locations

Sr. No.	Class according to Map classification	Coral Reef zones considered for the study
1	**Algal ridge** (The outer most visible part of the reef, which is heavily dominated by algae, especially *Sargassum sp*.)	**Lower Strata**
2	**Outer reef (**Outer reef mainly comprised of Reef edge, reef crest and reef slope, having continuous flushing of marine water during low tides)	
3	Inner reef (It is reef flat having shallow saucer shaped area fringed with the island on leeward side and with reef slope on the other side)	**Upper strata**
4	Reef Vegetation (All types of algae and seagrass on reef is considered under this class)	
5	Sandy reef (Upper strata of reef, which is covered by sand)	
6	Muddy reef (Upper strata of reef, which is covered by mud)	
7	Sandy beach (Sandy part on the island beyond the high tidal line, generally linear in nature)	**Above High-tide line**
8	Mangroves (Intertidal marsh vegetation towards the island / land)	**Intertidal Area**
9	Intertidal mudflats (mudflats having daily inundations)	
10	High-tidal mudflats (mudflats having inundations only during major high tides of full moon)	**Beyond hightide line, where water inundates rarely**
11	Coral pinnacle (Sharp edged coral formations, little away from the actual reef)	**Away from the actual reef**
12	Saltpans (Square to rectangle shaped man made water bodies for the production of salt)	**Manmade huge water bodies utilised for salt production**
13	Island (Soil beyond the high tide line, no influence of marine water)	

2. SAMPLING

Sampling Methodology (Plate 4)

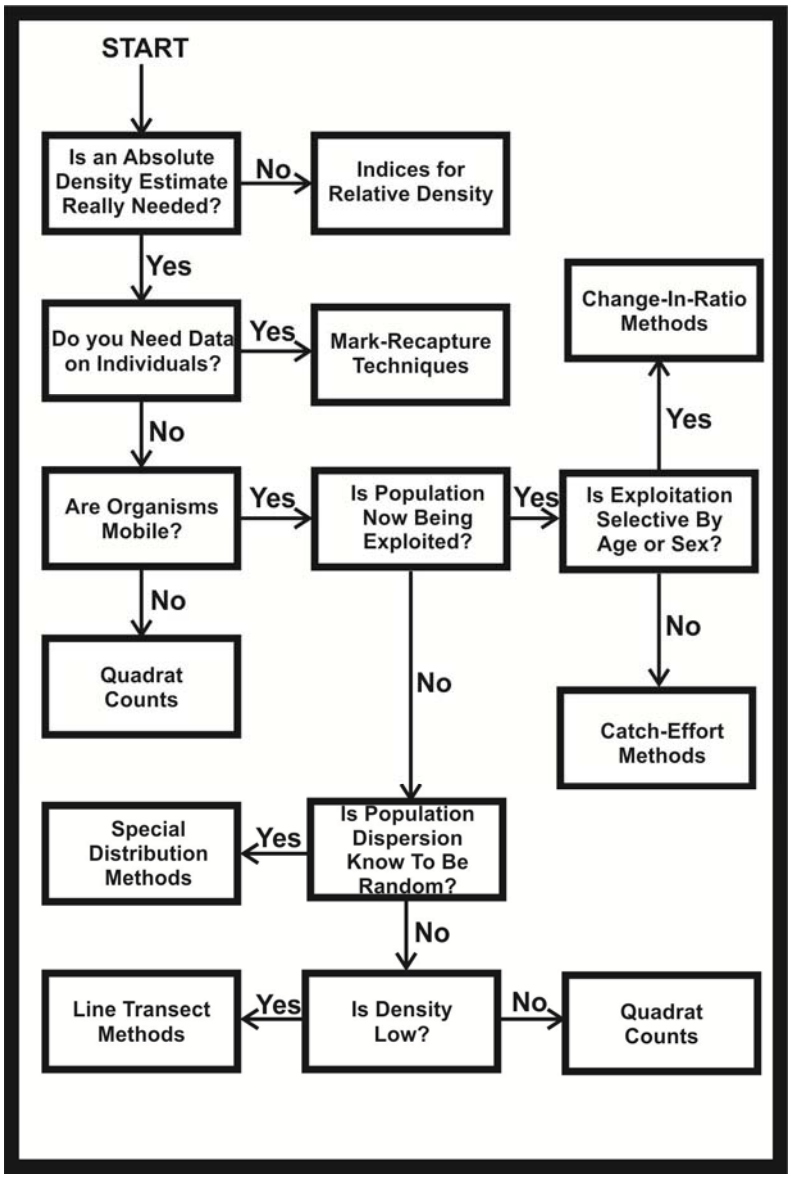
Reef Zones

Two major reef zones were identified *viz.* Lower strata and the Upper strata. The lower strata consist of algal ridge, reef slope, reef crest and reef edge, whereas upper strata consist of reef flat including reef vegetation, sandy reef and muddy reef.

Advantages of Quadrat Method with reference to the Coral Reefs of the Gulf of Kachchh

Quadrat sampling is the best method of sampling for sedentary life form (Krebs 1986). In the Gulf of Kachchh, the available time for sampling is very less during the low-tide, hence quadrats give more stability to the observations as well as to the observer. Though in the studies of corals the Line Intercept Transects (LIT) are well practiced (English *et al. 1994*). However, in the reefs of Gulf of Kachchh, where the data collection is carried out by walking on the reef and not by SCUBA or skin dive, the surrounding water becomes muddy (turbid) very fast and observations are hampered, hence the quadrats are the best suitable methodology to study the reef community, especially in the Gulf of Kachchh (Arthur, 2000). Hence, quadrat sampling method is used for the present study. Further, Krebs (1986) has given a comprehensive flow chart of the methodologies used in ecological sampling, which justifies the use of quadrat method to assess the coral community in the present study. The flow chart given by Krebs, (1986) is given below:

Fig: 4.1: Chart for the selection of best suitable Methodology (Source: Krebs, 1986)



Data Collection

Quadrats of 1x1 meter size with grids are the best suited in the Gulf of Kachchh area, as the visibility remains very clear in the 1x1 meter area and the sampling area being smaller identification of corals and other details on various parameters like substratum and associated fauna can be obtained comprehensively (Arthur, 2000).

The first sampling point (quadrat) was marked on the Google map of the location and the geo coordinates were taken to the field to start the sampling. All the subsequent quadrats

were taken at the distance of 20 meters from the previous in one direction parallel to the reef edge.

Parameters measured

Following Five major parameters which affect the coral cover as well as the recruitment were recorded for each quadrat. All the parameters were calculated by % area covered by that particular category.

Area sampled

The total sampled area was approximately 0.05% of the total reef area.

1. **Total % live coral cover:** Area covered by coral species/genera with their life forms within a quadrat was recorded by counting the grids that had live corals and converted to percentage.
2. **Algal cover:** Algae plays a major role in the health of corals as they do not allow the coral's symbiotic algae Zooxanthallae to photosynthesize and acts as a negative indicator for the coral health. Hence using the above mentioned grid method, algal cover of each quadrat was recorded.
3. **Substratum:** Substratum like Rocks, Rubbles and dead corals favours the settlement of coral larvae, and favours the growth, whereas mud doesn't allow their settlement and restricts the growth of corals**.** Hence, in same way percentage of substratum covered with rocks, rubbles and rocks were recorded.
4. **Other fauna:** Other fauna gives an account on the biological association within the reef ecosystem. Such associated fauna like Zooanthus, sea anemone, Bonellia *etc.* were counted through the same grid method, in each quadrat and converted into area covered.

Data Recording

- To simplify the data recording in terms of % benthic cover, the quadrat made of 1 x 1 meter PVC pipe was subdivided in to 100 small grids by the means of thin nylon string.
- All the variables / parameters within the quadrat were counted. The % coverage was calculated by counting the number of grids occupied by a single benthic form / substrate in the quadrat.
- Live corals were identified to the species level, coral cover was noted.
- The results were recorded in a well planned data sheet which listed all parameters to be collected for the present study purpose.

Materials Used:

1 meter PVC pipes (4 nos.) with L – shape fittings (4 nos.), thin nylon thread 22 meters, E trex Garmin GPS, Camera for recording observations, Data sheets, Google Map of the location with Latitude and Longitude, Compass for maintaining the angle parallel to reef.

Data sheet

Location……Name of the Observer……

Date……Site code……..

Time……GPS…….

Sr. No.	Categories	% Cover	Remarks
1.	Live coral		
•	Species 1		
•	2		
•	3		
•	4		
2.	Algae		
3.	Diseased coral		
4.	Bleached coral		
5.	Sea grass		
6.	Rock		
7.	Rubble		
8.	Sand		
9.	Mud		
10.	Biodiversity		

Belt Transect for Opisthobranch fauna

Belt transects were used for the study of associated fauna and their distribution in relation to a certain area as discussed by Hill *et al*. (2005). It records all the species found between the two lines and their numbers. The belt transect method is similar to the line transect method but gives information on abundance as well as presence or absence of species (Krebs, 1986). It may be considered as a widening of the line transects to form a continuous belt or series of quadrats.

Advantages

A belt transect supplies more data than a line transect. It gives data on the abundance of individual species and the relative dominance of species at different points along the line, as well as on their range. It also shows species range, and allows bar charts to be constructed showing how the abundance of each individual species changes within its range.

Area Sampled

At every 50th quadrat of the coral objective one belt transect of 20 meters x 1 meter was laid to find out associated fauna.

Data Collection

A transect line of 20 meters x 1 meter was laid at the 50th quadrat. At right angle a quadrat was laid to mark the distance of 1 meter. Total 37 transects were laid for associated fauna.

Parameters measured

For the purpose of this study data on opisthobranch fauna is only analysed whereas checklist of other associated is given in chapter 6. Species diversity and individual count of the species (for abundance) were considered for data recording.

Materials Used:

Measuring tape up to 20 meters, 1 meter PVC pipes (4 nos.) with L – shape fittings (4 nos.), E trex Garmin GPS, Camera for recording observations, Data sheets, Google Map of the location with Latitude and Longitude, Compass for maintaining the angle parallel to reef.

Water Analysis

The water temperature was measured using digital environment thermometer. The other water parameters were analysed using ready to use field analysis kit of Hanna and Eutech make model no: PCD 650. in which, after calibrating the instrument, the cathode can be directly dipped in to the sample water and the following parameters were recorded.

Salinity, pH and Dissolved Oxygen.

The turbidity was measured using turbidity meter of Eutech make model no TN 100. Single point data was collected, during the receding tide. The water quality was checked for

three seasons *i.e.* winter, post winter and summer for two years. Due to the unfavourable weather conditions the monsoon reading was not possible.

3. POST SAMPLING

The data analysis was carried out in the following pattern

- **The data entry** was carried out in MS. Excel 2007, for the analysis. Basic analysis such as mean, Standard deviation, average *etc.* was carried out using MS. Excel 2007. Percentages cover of all the benthic community (corals, vegetation and substrate) was calculated.
- **t – Test** between the live coral cover of upper strata and lower strata for each location was performed using Prism 3.0.
- **Frequency Distribution Graph and ANOVA** for live coral cover of lower strata was performed using Prism 3.0
- **Pearson's correlation Index** was calculated using Prism 3.0
- **Frequency of Occurrence** for all the species were calculated using the formula Frequency of Occurrence (*f*) = (occurrence of species *x* in no. of transects / total transects) (Krebs 1986)
- **Relative frequency of the species (*%f*)** was calculated with the formula, Relative frequency (*%f)* = f of χ species / $\sum f$ * 100 (Krebs 1986)
- **Jaccard's Species Index of Similarity** was calculated between six locations for coral richness as well as opisthobranch species richness using the following formula (Michael 1986) *Js* = J/(a+b-J)

  Where J is number of species common at two sites, a is species richness at one site and b is species richness at second site.
- **Relative abundance** of the species was calculated as Relative Abundance (%RA) = (Total no of colonies of *x* species / Total colonies (N) of all species) * 100

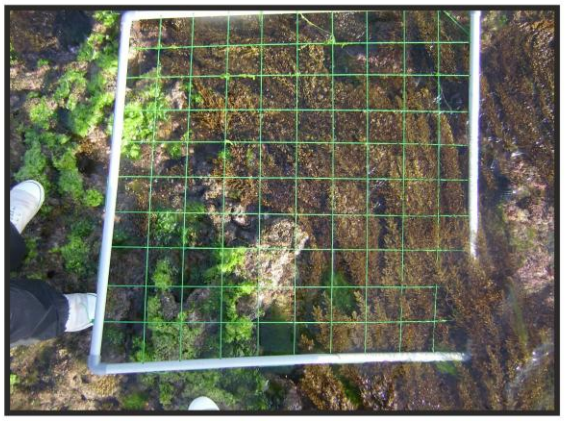
- **Relative density** is the study of numerical strength of a species in relation to the total number of individuals of all the species and is calculated as: Relative density (RD) = Number of individual of χ species / Number of individual of all the species X 100 (Michael 1986).
- **Important Value Index (IVI)** was calculated based on following formula IVI = $\sum$ (%RD + *%f*) where % RD is the relative density of χ species, % *f* is the relative frequency of χ species. (Fowler 2000)
- The species diversity index of opisthobranchs was calculated according to the **Shannon–Weiner** formula, (Michael 1986), $H' = \sum Pi \log epi$, Where Pi is the proportion of the ith species in the collection and H'is the diversity of a theoretically infinite population.
- The **evenness** was calculated by following formula Evenness (e) = $\sum Pi \log epi$ /log of total species (N) (Michael 1986)**.**

Field Work

Field visits were carried out from November 2008 to March 2010. Total 10 field visits were carried out during the study, with each one of seven to ten days. All the locations were visited during each field visit.

Plate 4. Methodology according to various objectives

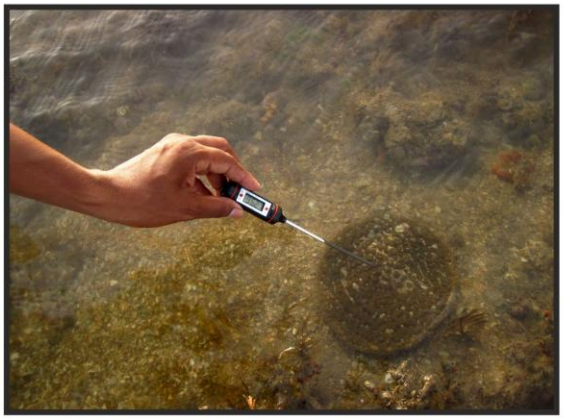
Belt Transect for coral reef associates



Quadrats for Corals

Search for coral reef associates

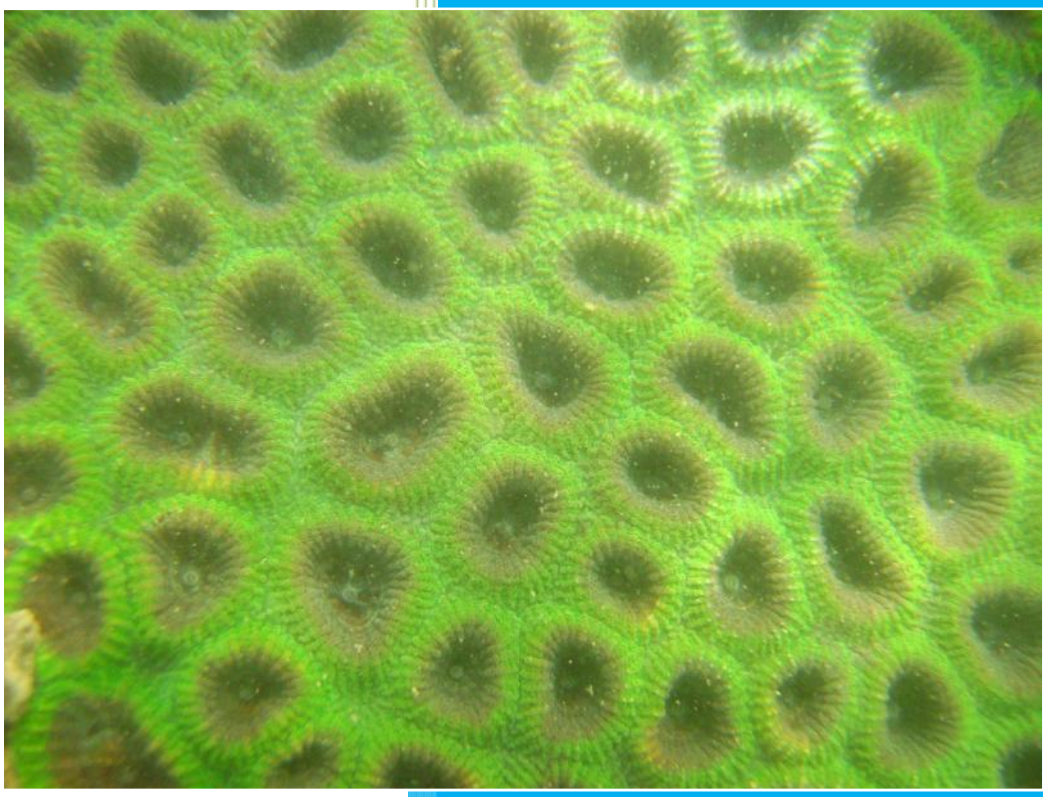
Water Quality Analysis (D.O.)



Water Quality Analysis (Temp.)

Water Quality Analysis (pH)

5. CORALS



CHAPTER 5
CORALS

5.1 INTRODUCTION

Distribution of corals in the Gulf of Kachchh (GoK) is confined to its southern shore. To protect these corals, Government of Gujarat declared the area as Marine National Park and Sanctuary (MNP and S) through first notification in 1982 and then several other notification at later dates. In this Marine National Park and Sanctuary, total fourty two locations (Jani and Asari 2004) have been identified, which have live coral occurrences. Till date most of the studies of corals and coral reef of this area were restricted to the taxonomy (Patel, 1985; Pillai and Patel, 1988; Venkatraman, *et al.*, 2003; Satyanarayana, 2009). However, the overall status of coral reefs of the MNP and S, is not documented. Hence, this study was planned to assess the current status of the coral reefs of the MNP and S. Six coral occurring sites, 2 in east (Pirotan and Goose), 2 in the central (Narara and Kalubhar) and 2 (Poshitra and Asaba Pir) in west MNP and S were selected for the study.

5.2 RESULTS

Based on the data collected, following results were obtained for the six study locations. The results contain comparative account of the lower and upper strata for the benthic coverage (%) of live corals along with other benthic cover classes for each location. The results also include species richness and relative frequency. At the end, status of the corals at six locations is compared.

Pirotan Island

Reef Profile (Map 5.1)

Pirotan island with one of the eastern most settlement of corals in the Gulf of Kachchh, is an oval shaped island with total reef area exposed, during the low tide of 61,67,377 m^2. Here the major intertidal habitats were algal ridge, mangroves, coral reefs, mudflats and sandy beaches (Map 5.1). The concentration of mangroves and mudflats were on the central part of the island, whereas coral reef extended along the northeastern, northern and northwestern part of the island. The inner reef area extend up to southwest and southern part of the island. The reef area covered approximately 45% of the total intertidal area, whereas the mudflats and mangroves together covered 55% of the total intertidal area. The reef is a typical intertidal fringing type of reef, consisting of reef flat, reef crest and reef slope. The reef slope gets exposed only during the minus (negative) tides. The intertidal reef flat was dominated by shallow water logged pools. Growth of encrusting corals was observed on the inner margins of the pool. From December to April, these tidal pools and the reef crest showed hyper dominance of the algae, especially of *Sargassum spp.* Healthy live corals were observed on the northern crest of the reef, where the submerged light house is situated, while the north-western reef had low coral cover compared to the northern reef of the site.

Species Richness (Table 5.1)

Of the total 258 quadrats laid on Pirotan island, in the upper strata *i.e.* reef flat, live corals occurred in 47% quadrats. While, in lower strata 78% quadrats recorded live corals. Thus, average frequency of live corals in the study location was 62 percent.

Within the sampled area, total 18 species of hard corals were recorded, of which 11 were present on the Upper strata while 16 were recorded from the Lower strata. The Jaccard's species similarity index between these two strata was 0.5. Only one species

Parycyathus stokessi was recorded outside the sampling area, agreegating the total richness to 19 species.

Table 5.1: A comparison of habitat characteristics and coral community between the upper and lower strata of the reef at Pirotan island

Sr. No.	Parameters	Upper	Lower	Average / Total
1	Total quadrats laid	96	162	258
2	Quadrats with presence of Live Coral	45	127	172
3	Frequency of occurrence (%)	46.87	78.39	62.63
4	Species Richness (within the sampled area)	11	16	18
5	Additional species (outside the sampled area)			1
6	Total Species Richness			19
7	Jaccard's similarity Index			0.5
8	Probality value of t - Test of Live corals between two strata			**0.001
9	Benthic cover of Live Coral area (%)	10.2	18.3	14.3
10	Benthic cover of Algae (%)	24.1	32.5	28.3
11	Benthic cover of Mud (%)	1.5	0.2	0.8
12	Benthic cover of Sand (%)	21.3	16.6	18.9
13	Benthic cover of Rock (%)	35.3	23.3	29.3
14	Benthic cover of Rubble (%)	7.5	8.1	7.8
15	Benthic cover of Other fauna (%)	0.1	1.0	0.5

** Highly significant

Benthic Cover (Table 5.1, Fig 5.1)

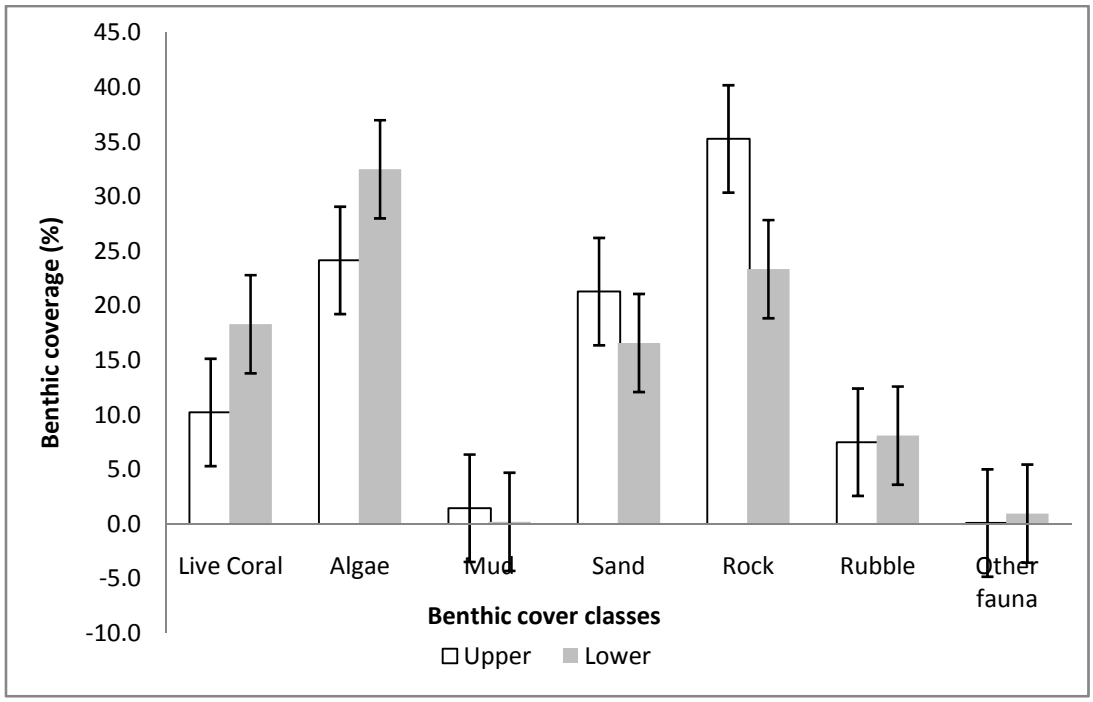
Seven parameters were considered for the benthic coverage in the quadrats for both the upper and the lower strata.

At Pirotan average live coral cover was 14.3%. The live coral coverage in the lower strata 18.3% was significantly higher than upper strata (10.2%) ($P < 0.01$, $df = 267$).

32.5% algal cover was noted in the lower strata, compared to 24.1% in the upper strata. Presence of mud was negligible both on the upper strata (1.5%), and lower strata (0.2%), while sand coverage was 21.3% in the upper strata, compared to 16.6% in the lower strata. Coverage of rock was numerically high in the upper strata (35.3%) than the

lower strata (23.3%), while benthic coverage of rubbles showed negligible difference between the upper (7.5%) and lower strata (8.1%). Associated sedentary fauna such as Sea anemone (*Stichodactyla haddoni*) and Zooanthus (*Polythoa sp.*) (Chapter 6) covered 1% of the benthic substrate in the lower strata compared to very low coverage in upper strata (0.1%).

Fig: 5.1: Benthic Cover (% ± SEM) of upper and lower strata at Pirotan



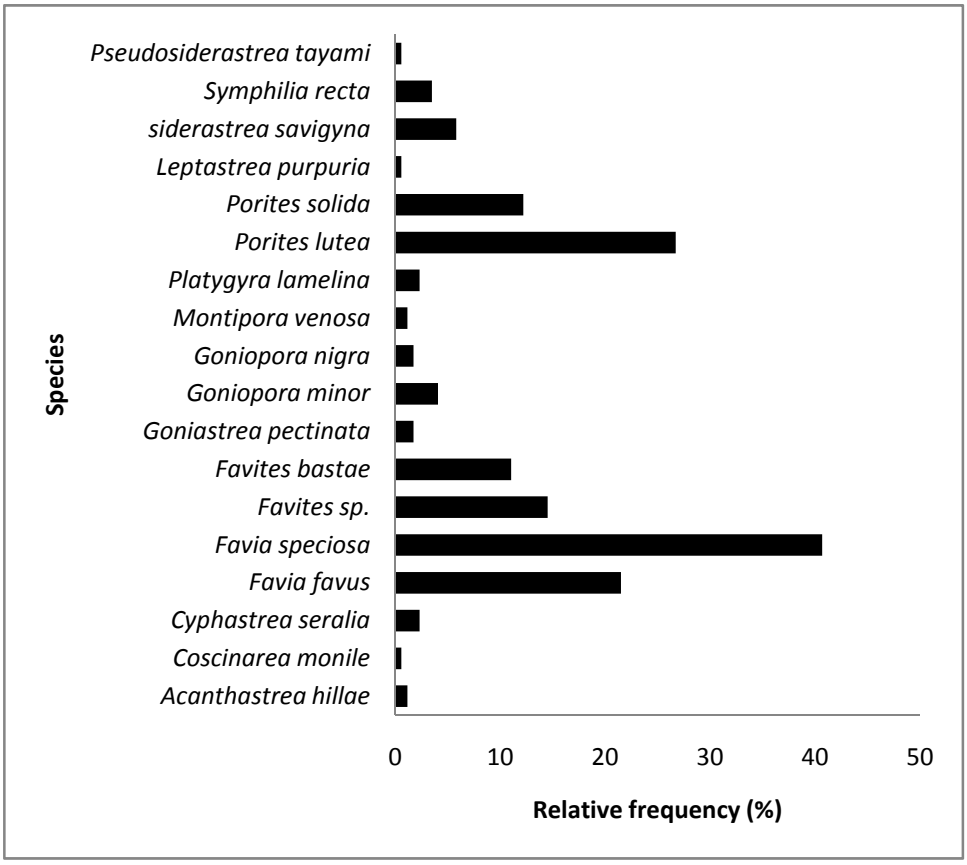
Relative Frequency of occurrence of hard coral species at Pirotan (Table 5.2, Fig 5.2)

Favia speciosa was the most frequently occurring species with relative frequency of 41% followed by *Porites lutea* (27%) and *Favia favus* (22%). These were followed by two species of *Favites viz. Favites sp.* (15%) and *Favites bastae* (11%). Nine species *viz. Pseudosiderestrea tayami, Leptastrea purpuria, Platygyra lamelina, Montipora venosa, Goniopora nigra, Goniastrea pectinata, Cyphastrea serralia, Coscinarea monile* and *Acanthastrea hillae* showed very low occurrence.

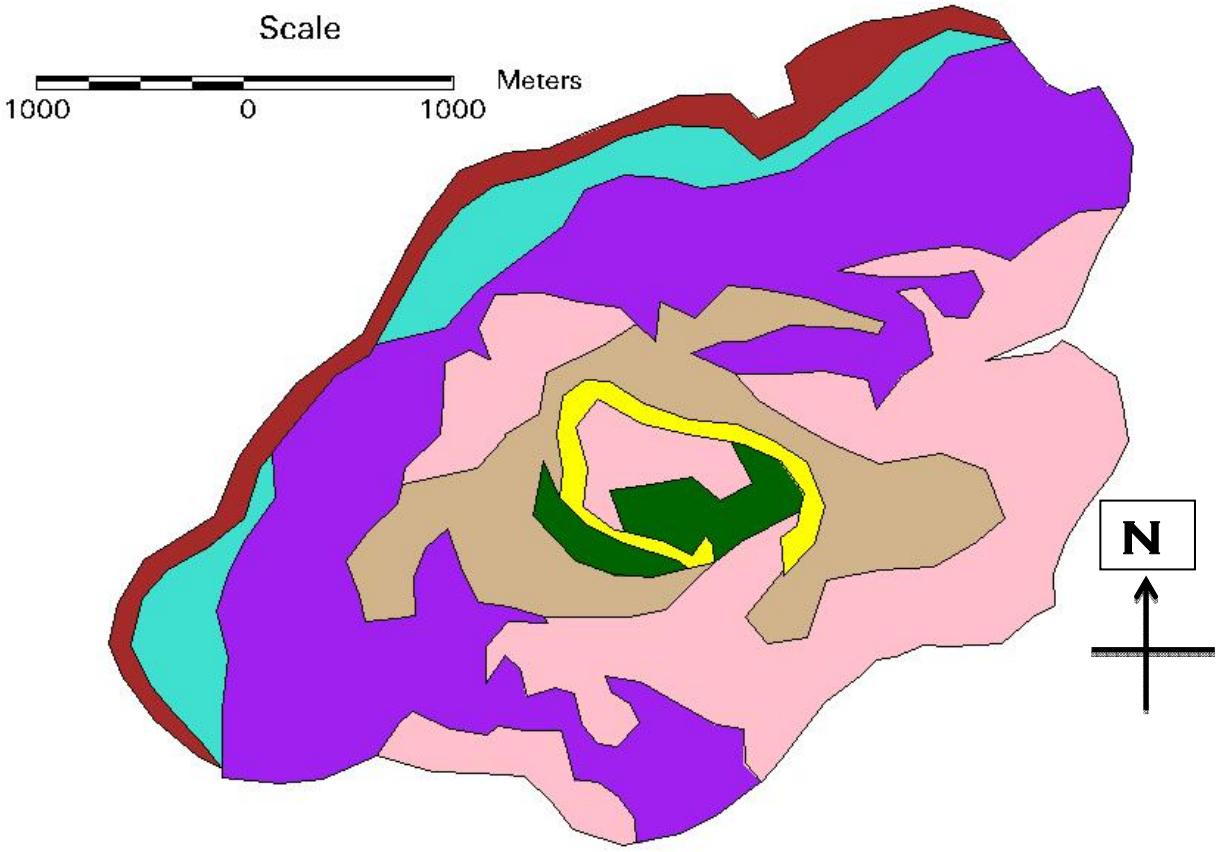
Table 5.2: Relative Frequency of hard coral species at Pirotan

Sr. No.	Species	Relative frequency (%)
1	*Acanthastrea hillae*	1.2
2	*Coscinarea monile*	0.6
3	*Cyphastrea seralia*	2.3
4	*Favia favus*	21.5
5	*Favia speciosa*	40.7
6	*Favites sp.2*	14.5
7	*Favites bastae*	11.0
8	*Goniastrea pectinata*	1.7
9	*Goniopora minor*	4.1
10	*Goniopora nigra*	1.7
11	*Montipora venosa*	1.2
12	*Platygyra lamelina*	2.3
13	*Porites lutea*	26.7
14	*Porites solida*	12.2
15	*Leptastrea purpuria*	0.6
16	*Siderastrea savigyna*	5.8
17	*Symphilia recta*	3.5
18	*Pseudosiderastrea tayami*	0.6

Fig: 5.2: Relative Frequency (%) of hard coral species at Pirotan



Pirotan



Colour Code	Color/catagory		Area (sq mtr)
1.		Algal ridge	894553.4
2.		Outer Reef	1145773.7
3.		Inner Reef	5021504.8
4.		Sandy beach	281114.0
5.		Mangroves	409555.2
6.		Intertidal mudflats	3985837.0
7.		Island	0.0
8.		Reef vegetation	0.0
9.		High tidal mudflats	0.0
10.		Sandy reef	0.0
11.		Coral Pinnacle	0.0
12.		Muddy reef	1892374.6
13.		Salt Pan	0.0
	Total Area (Square meter)		**13630712.6**

Goose Reef

Habitat Profile (Map 5.2)

Goose is a submerged reef, devoid of any hightidal land class and gets exposed only during low tides. The reef is situatued just opposite Sikka, between the jetties of GSFC and Reliance Industries. The shape of the reef is oval and has two central patches of sand. Though being submerged during high tide, the reef has the geomorphological characteristics of the fringing type of reefs, having reef flat (upper strata) on the leeward side and reef crest and reef slope (lower strata) on the seaward side. Major land cover classes were Algal ridge, Outer reef, Inner reef, Sandy beach, Reef vegetation and muddy reef. The outer strata consist of two classes *i.e.* Algal ridge and the outer reef. These two classes together covered 17% area of the total reef. While inner reef (upper strata) consisted of 52% of the total intertidal habitats. The total intertidal area of the reef was 9139327 m^2 (Map 5.2).

Species Richness (Table 5.3)

Out of 274 quadrats laid on the reef, in the upper strata, 77% quadrats had live corals. Frequency of occurrence of live corals of lower strata (78%) was at par with that of upper strata (77%).

Within the sampled area, 17 species of hard corals were recorded, of which 16 were present on the lower strata and 14 on upper strata. The Jaccard's species similarity index between these two strata was 0.76. Only one species *Parycyathus stokessi* was recorded outside the sampling area, aggregating the total Species richness to 18 species.

Table: 5.3: A comparison of habitat characteristics and coral community between the upper and lower strata at Goose Reef

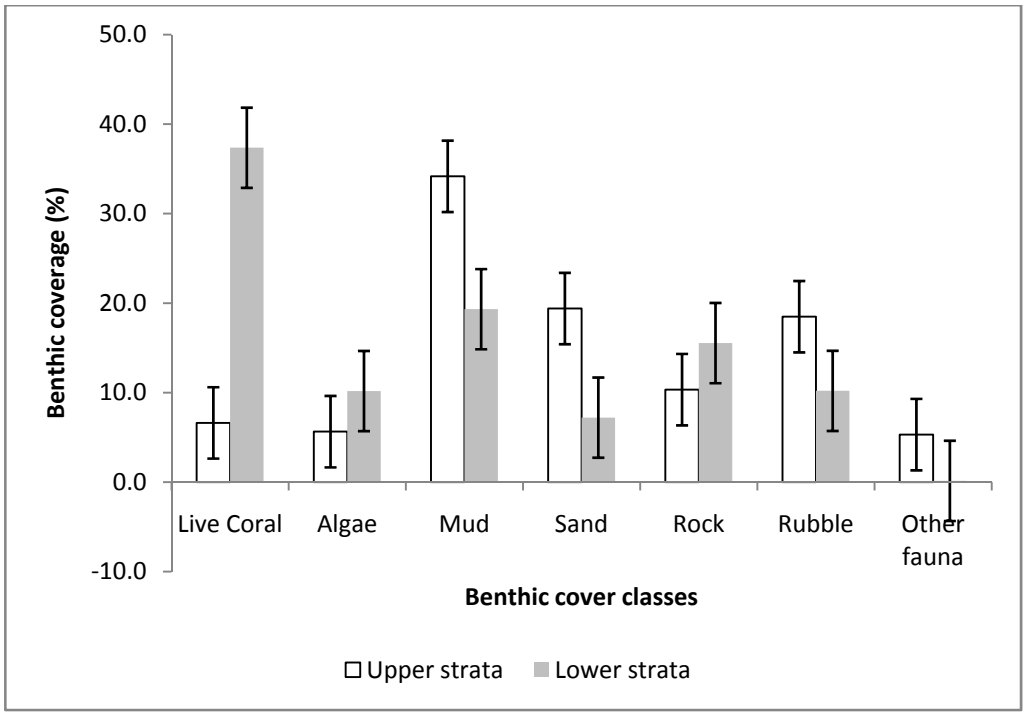
Sr. No.	Parameters	Upper	Lower	Average / Total
1	Total quadrats laid	112	162	274
2	Quadrats with presence of Live Coral	86	127	213
3	Frequency of occurrence	76.7	78.4	77.6
4	Species Richness (within the sampled area)	16	14	17
5	Additional species (outside the sampled area)			1
6	Total Species Richness			18
7	Jaccard's Similarity Index			0.76
8	Probality value of t - Test of Live corals between two strata			**0.001
9	Benthic cover of Live Coral (%)	6.6	37.4	22.0
10	Benthic cover of Algae (%)	5.6	10.2	7.9
11	Benthic cover of Mud (%)	34.2	19.3	26.8
12	Benthic cover of Sand (%)	19.4	7.2	13.3
13	Benthic cover of Rock (%)	10.3	15.5	12.9
14	Benthic cover of Rubble (%)	18.5	10.2	14.3
15	Benthic cover of Other fauna (%)	5.3	0.1	2.7

** Highly Significant

Benthic Cover (Table 5.3 Fig 5.3)

The average live coral cover at Goose reef was 22%. The live coral coverage of lower strata (37.4%) was significantly high compared to upper strata (6.6%) ($P < 0.01$, $df = 273$). The algal coverage in the lower strata was 10.2% compared to 5.6% of the lower strata. The deposition of mud was numerically high in the upper strata (34.2%) compared to the lower strata (19.3%). Sand cover was also numerically recorded high in the upper strata (19.4) than the lower strata (7.2) while coverage of rock was higher in lower strata (15.5%) compared to lower strata (10.3%). Other associates, *Polythoa spp*. showed significant coverage (5%) in the upper strata.

Fig: 5.3: Benthic Cover (% ± SEM) of upper and lower strata at Goose



Relative Frequency of occurrence of hard coral species at Goose (Table 5.4 Fig 5.4)

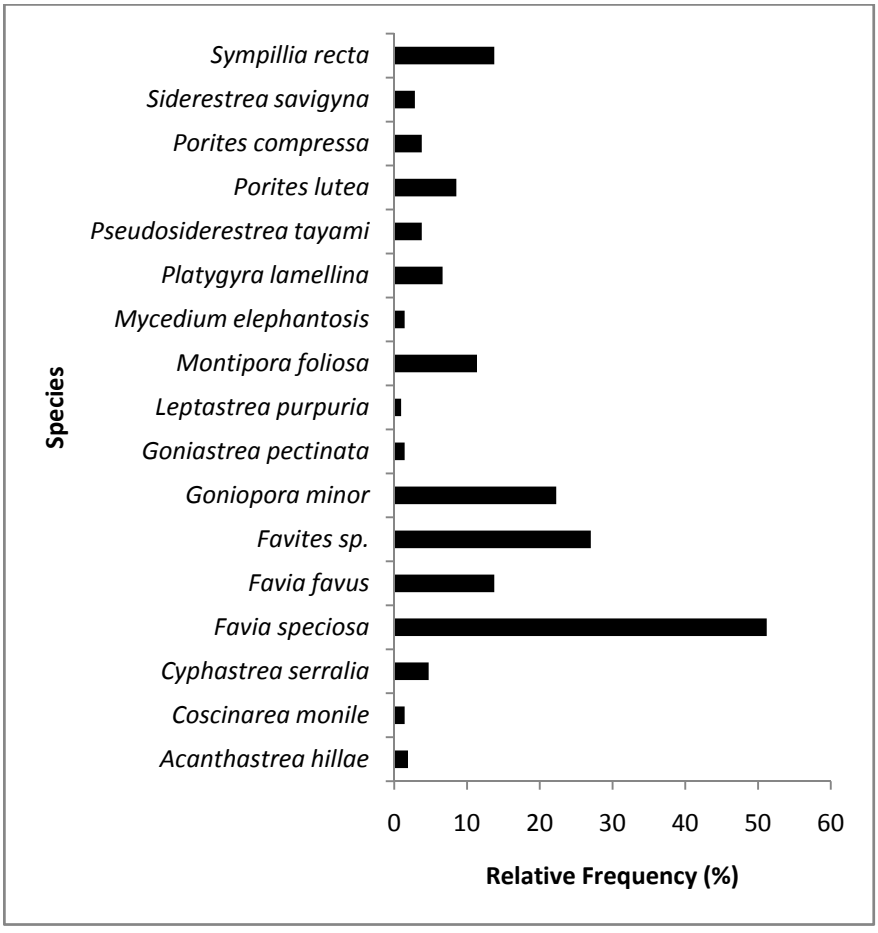
At Goose reef also *Favia speciosa* was found to be the most frequently occurring species with relative frequency of 51%. This was followed by *Favitess sp2* and *Goniopora minor* with relative frequency of 27 and 22 respectively. *Symphillia recta*, and *Favia favus* showed equal relative frequency *i.e.* 14% each. While *Leptastrea purpuria, Goniastrea pectinata, Mycedium elephantosis, Coscinarea monile* and *Acanthastrea hillae* showed very low occurrence (Fig 5.4).

Table: 5.4: Relative Frequency of Occurrence of coral species (in %) at Goose reef

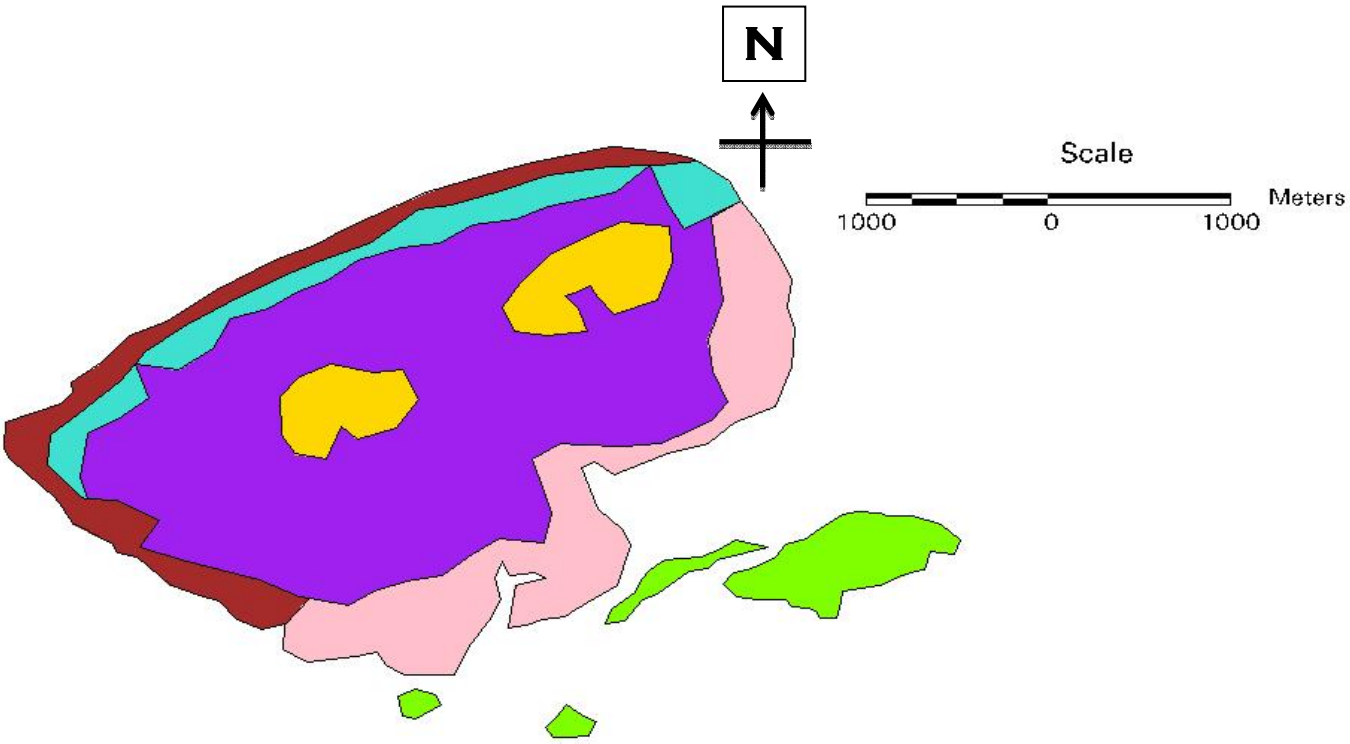
Sr. No.	Species	Relative Frequency (%)
1	*Acanthastrea hillae*	1.9
2	*Coscinarea monile*	1.4
3	*Cyphastrea serralia*	4.7
4	*Favia speciosa*	51.2
5	*Favia favus*	13.7
6	*Favites sp. 2*	27.0
7	*Goniopora minor*	22.3
8	*Goniastrea pectinata*	1.4

9	*Leptastrea purpuria*	0.9
10	*Montipora foliosa*	11.4
11	*Mycedium elephantosis*	1.4
12	*Platygyra lamellina*	6.6
13	*Pseudosiderestrea tayami*	3.8
14	*Porites lutea*	8.5
15	*Porites compressa*	3.8
16	*Siderestrea savigyna*	2.8
17	*Sympillia recta*	13.7

Fig: 5.4: Relative Frequency of Occurrence of coral species (in %) at Goose reef



Goose



Colour Code	Colour/catagory		Area (sq mtr)
1.		Algal ridge	826946.7
2.		Outer Reef	706517.9
3.		Inner Reef	4809035.8
4.		Sandy beach	691572.1
5.		Mangroves	0
6.		Intertidal mudflats	1520049.6
7.		Island	0
8.		Reef vegetation	585205.2
9.		High tidal mudflats	0
10.		Sandy reef	0
11.		Coral Pinnacle	0
12.		Muddy reef	0
13.		Salt Pan	0
	Total Area (Square meter) **9139327.5**		

Narara

Habitat Profile (Map 5.3)

Narara was once considered as an island and hence still pronounced as beyt (*i.e.* an island). Due to the development of saltworks and other human activities, it is now well connected with the main land. The intertidal reef area of the site is one of the largest amongst such areas in Gulf of Kachchh. The site has typical intertidal fringing reef that can be divided in to reef flat, reef crest and reef slope. The live corals in the reef were found sparsely at the junction of reef flat and reef slope to the seaward margins of the reef slope. However, the concentration of live corals was observed in some parts of the eastern, northern and western edges of the reef crest. Total nine land cover classes were observed at Narara reef. Saltpans covered maximum 89.2 km^2 area. The Lower strata, consisting of algal ridge and outer reef consisted of 17% of the intertidal areas, whereas the inner reef and sandy reef together covered 9% of the total intertidal area. Due to the dredging of the reef for laying pipeline for the transport of crude oil, several dead coral skeletons can be found on the upper intertidal areas. Such boulders were found to be as huge as two to three meters in circumference. The major intertidal habitat classes at Narara were coral reef, mudflats, intertidal sand floors, sandy beaches and mangroves.

Species Richness (Table 5.5 Fig 5.5)

In the upper strata *i.e.* reef flat, live corals occurred in 32% quadrats, while the lower strata 39% quadrats recorded live coral. Hence the average frequency of occurrence of live corals on the Narara was 36.15%.

Within the sampled area 19 species of hard corals were recorded, of which 15 were present on the upper strata and 11 were recorded from lower strata. The Jaccard's species similarity index between these two strata was 0.44. Only one species *Parycyathus stokessi* was recorded outside the sampling area, making the total species richness of 20 species.

Table 5.5: A comparison of habitat characteristics and coral community between the upper and lower strata of the reef at Narara

Sr. No.	Parameters	Upper Strata	Lower strata	Total / Average
1	Total quadrats laid	289	175	464
2	Quadrats with presence of Live Coral	95	69	164
3	Frequency of occurrence	32.87	39.43	36.15
4	Species Richness (within the sampled area)	15	11	19
5	Additional species (outside the sampled area)			1
6	Total Species Richness			20
7	Jaccard's Similarity Index			0.44
8	Probality value of t - Test of Live corals between two strata			0.0018**
9	Benthic cover of Live Coral (%)	2.17	4.85	3.51
10	Benthic cover of Algae (%)	29.57	33.68	31.625
11	Benthic cover of Mud (%)	4.6	1.1	2.85
12	Benthic cover of Sand (%)	17	2.4	9.7
13	Benthic cover of Rock (%)	34	43	38.5
14	Benthic cover of Rubble (%)	11.1	14.4	12.75
15	Benthic cover of Other fauna (%)	1	1.03	1.015

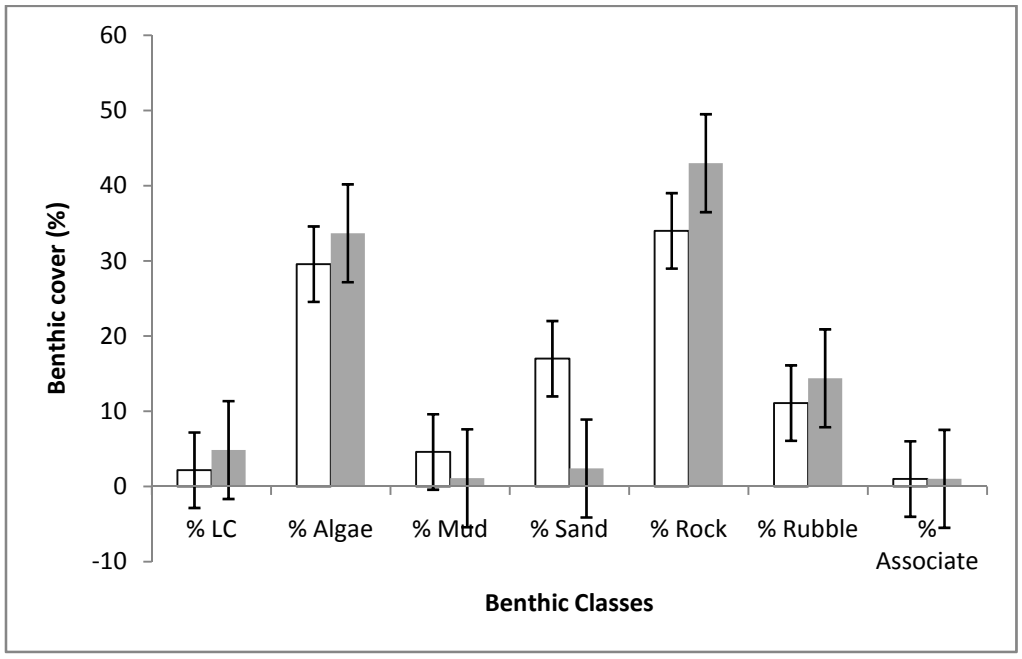
** Highly Significant

Benthic Cover (Table 5.5 Fig 5.5)

Seven Parameters were recorded for the benthic coverage in the quadrats for both upper and lower strata at Narara.

Average live coral cover percentage at Narara was 3.51% lowest amongst the 6 studied locations. The coral cover of the lower strata though low, (4.85%), was significantly different than that of upper strata (2.17%) ($P < 0.01$, $df = 463$). Algal cover marginally differed with 33.68% in lower strata and 29.57 % in the upper strata. Rock coverage dominated the lower strata with 43% compared to 34% of the upper strata. Rubbles were having almost similar coverage 11.1% in the upper strata and 14.4% in the lower strata.

Fig 5.5: Benthic Cover (% ± SEM) of upper and lower strata at Narara



Relative Frequency of occurrence of hard coral species at Narara (Table 5.6 Fig 5.6)

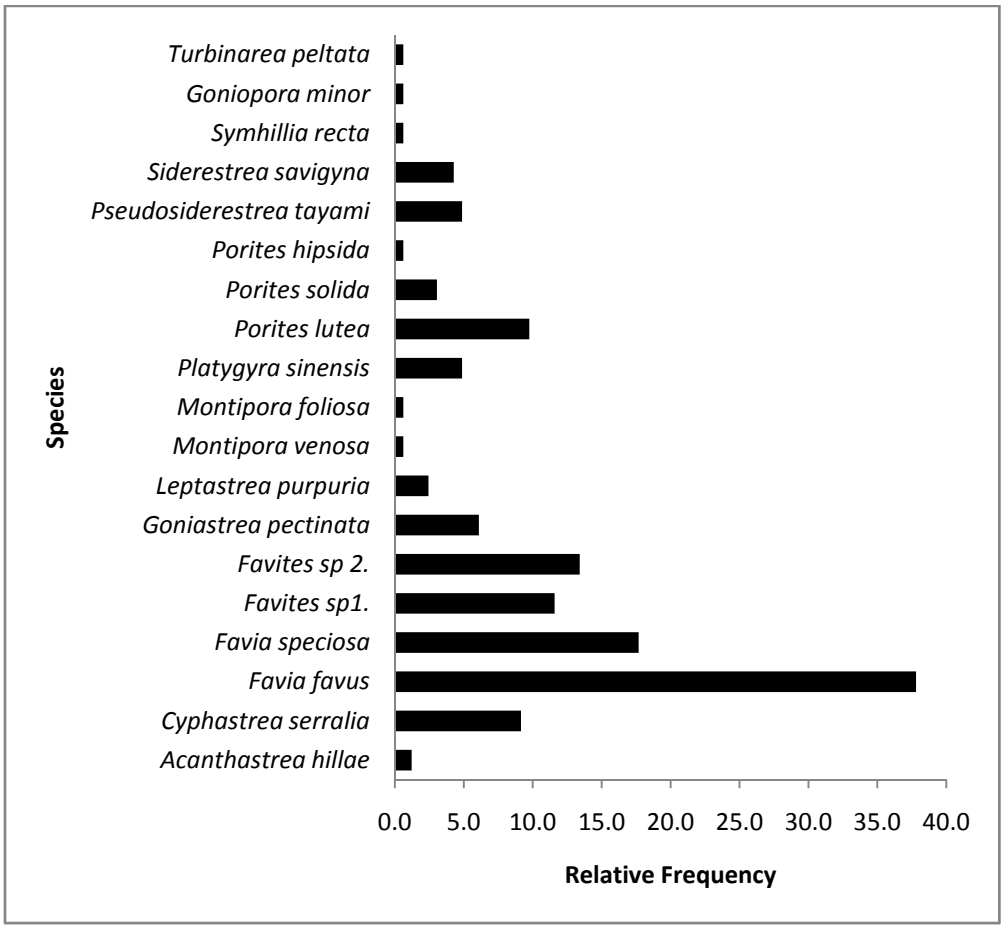
Favia favus, was the most frequently occurring species with relative frequency of 37.8%. *Favia specieosa* and two species of *Favites* were found to be frequently occurring species with relative frequency of 17.7, 13.4 and 11.6% respectively. These were followed by *Porites lutea* with relative frequency of 9.8%. Seven species viz. *Turbinaria peltata, Goniopora minor, Symphillia recta, Porites hispida, Montipora foliosa, Montipora venosa and Acanthastrea hillae* showed very low occurrence.

Table 5.6: Relative Frequency of Occurrence of hard coral species (in %) at Narara

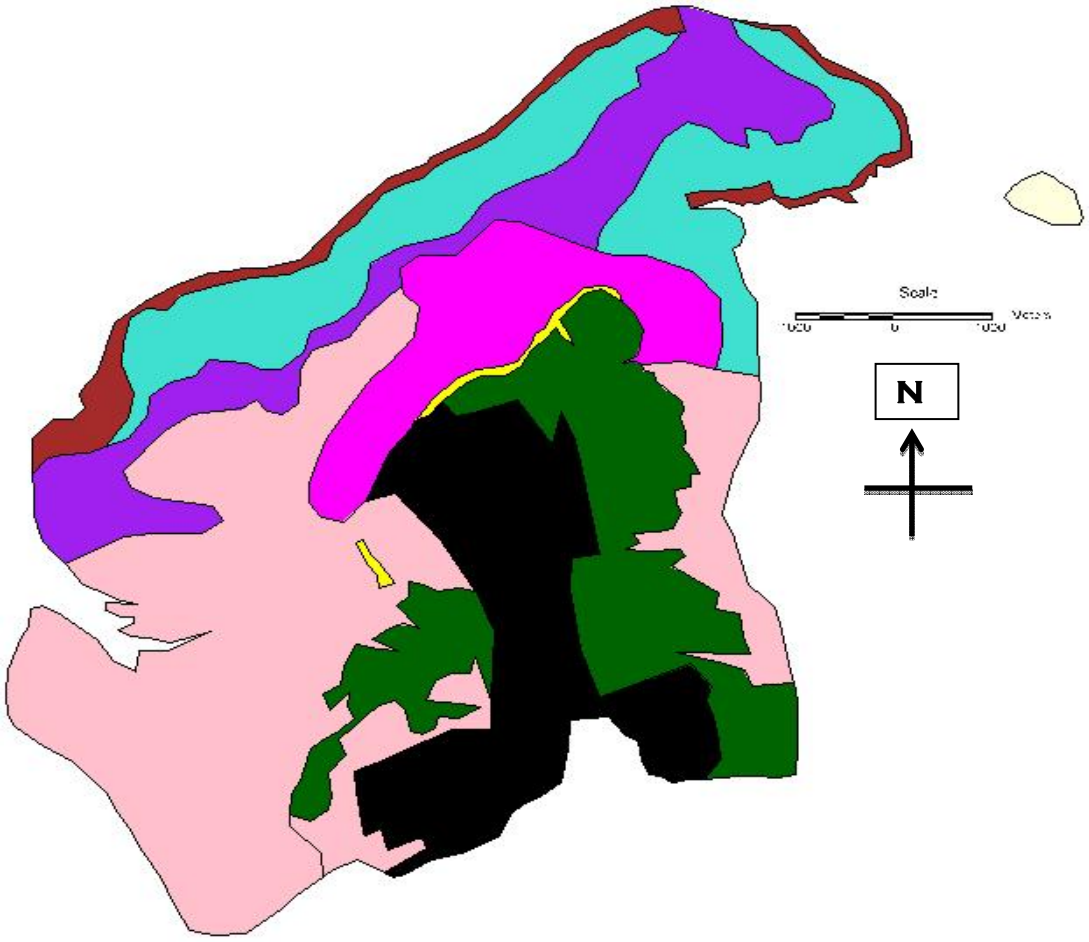
Sr. No.	Species	Relative frequency (%)
1	*Acanthastrea hillae*	1.2
2	*Cyphastrea serralia*	9.1
3	*Favia favus*	37.8
4	*Favia speciosa*	17.7
5	*Favites sp.1*	11.6
6	*Favites sp.2*	13.4
7	*Goniastrea pectinata*	6.1
8	*Leptastrea purpuria*	2.4
9	*Montipora venosa*	0.6
10	*Montipora foliosa*	0.6

11	*Platygyra sinensis*	4.9
12	*Porites lutea*	9.8
13	*Porites solida*	3.0
14	*Porites hipsida*	0.6
15	*Pseudosiderestrea tayami*	4.9
16	*Siderestrea savigyna*	4.3
17	*Symhillia recta*	0.6
18	*Goniopora minor*	0.6
19	*Turbinarea peltata*	0.6

Fig: 5.6: Relative Frequency of Occurrence of coral species (in %) at Narara



Narara



Colour Code	Colour/catagory		Area (sq mtr)
1.		Algal ridge	2290245.2
2.		Outer Reef	8948976.7
3.		Inner Reef	6552632.0
4.		Sandy beach	312286.8
5.		Mangroves	8904324.5
6.		Intertidal mudflats	20210809.8
7.		Island	0
8.		Reef vegetation	0
9.		High tidal mudflats	0
10.		Sandy reef	5052361.3
11.		Coral Pinnacle	339771.6
12.		Muddy reef	0
13.		Salt Pan	8926562.4
	Total Area (Square meter)		**61537970.4**

Kalubhar

Habitat Profile (Map 5.4)

Kalubhar is one of the largest island having a total area of 68.67 km^2 including the inter-tidal areas. It is diamond shaped, with very close approach to the Vadinar Port and Essar Jetty. Total nine land cover classes were recorded on this island. They are Algal ridge, Outer reef, Inner reef, Sandy beach, Mangroves, Intertidal mudflats, Island, Hightidal mudflats and Sandy reef. The southern inter-tidal area is heavily dominated by mudflats covering an area of 231.75 km^2. The reef is situated at the northern side of the island, having 4073422 m^2 area as outer reef and 4804775 m^2 as inner reef. The lower strata comprised of algal ridge and outer reef consisted of 8% of the intertidal area. Whereas the upper strata comprised of inner reef covered 6.9% of the total intertidal area.

Species Richness (Table 5.7 Fig 5.7)

Live corals were recorded in 50% of the quadrats of the upper strata, and 60% of quadtrates in lower strata.

Within the sampled area 21 species of hard corals were recorded, of which 11 were present in the upper strata and 16 in the lower strata. Three species were confined to the reef flat only whereas five species were confined to slope and crest. Two species *viz*. *Favia pallida* and *Parycyathus stokessi* were recorded outside the sampled area, hence the total coral species richness at Kalubhar was 23 species. The Jaccard's species similarity index between these two strata was 0.42 (Table 5.7).

Table: 5.7: A comparison of habitat characteristics and coral community between the upper and lower strata of the reef at Kalubhar island

Sr. No.	Parameters	Upper Strata	Lower strata	Total / Average
1	Total quadrats laid	348	332	680
2	Quadrats with presence of Live Coral	174	208	382
3	Frequency of Occurrence (%)	50	60	56
4	Species Richness (within the sampled area)	11	16	21
5	Additional species (outside the sampled area)			2
6	Total Species Richness			23
7	Jaccard's Similarity Index			0.42
8	Probality value of t Test of Live corals between two strata			0.0018**
9	Benthic cover of Live Coral (%)	11.31	23.28	17.30
10	Benthic cover of Algae (%)	49.61	42.87	46.24
11	Benthic cover of Mud (%)	0.51	1	0.76
12	Benthic cover of Sand (%)	15.19	4.98	10.09
13	Benthic cover of Rock (%)	17.34	25	21.17
14	Benthic cover of Rubble (%)	5.53	2.89	4.21
15	Benthic cover of Associate (%)	0.47	0	0.24

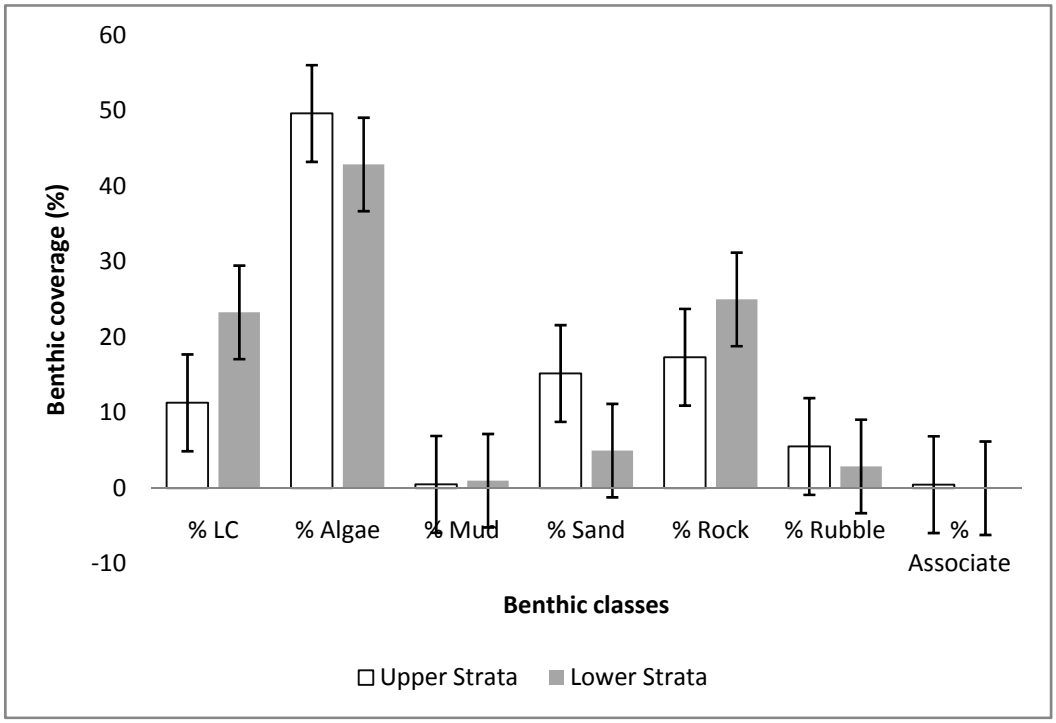
** Highly Significant

Benthic Cover (Table 5.7 Fig 5.7)

Total 7 Parameters were recorded for the benthic coverage in the quadrats for both upper and lower strata at Kalubhar.

The average live coral cover was 17. 3%, with percent coverage of the lower strata (23.28%) significantly higher than the upper strata (11.31%) ($P<0.01$, $df = 679$). The most dominant benthic cover class was algae, covering 49% in the upper strata and 42.87% in the lower strata. Coverage of rocks was 25% in the lower strata and 17.34% in the upper strata, while rubble cover was 5.53% in the upper strata compared to 2.89% in the lower strata. Sand coverage was numerically high 15.19% compared to 4.98% of lower strata.

Fig: 5.7: Benthic Cover (% ± SEM) of upper and lower strata at Kalubhar



Relative Frequency of Occurrence of hard corals at Kalubhar (Table 5.8 Fig 5.8)

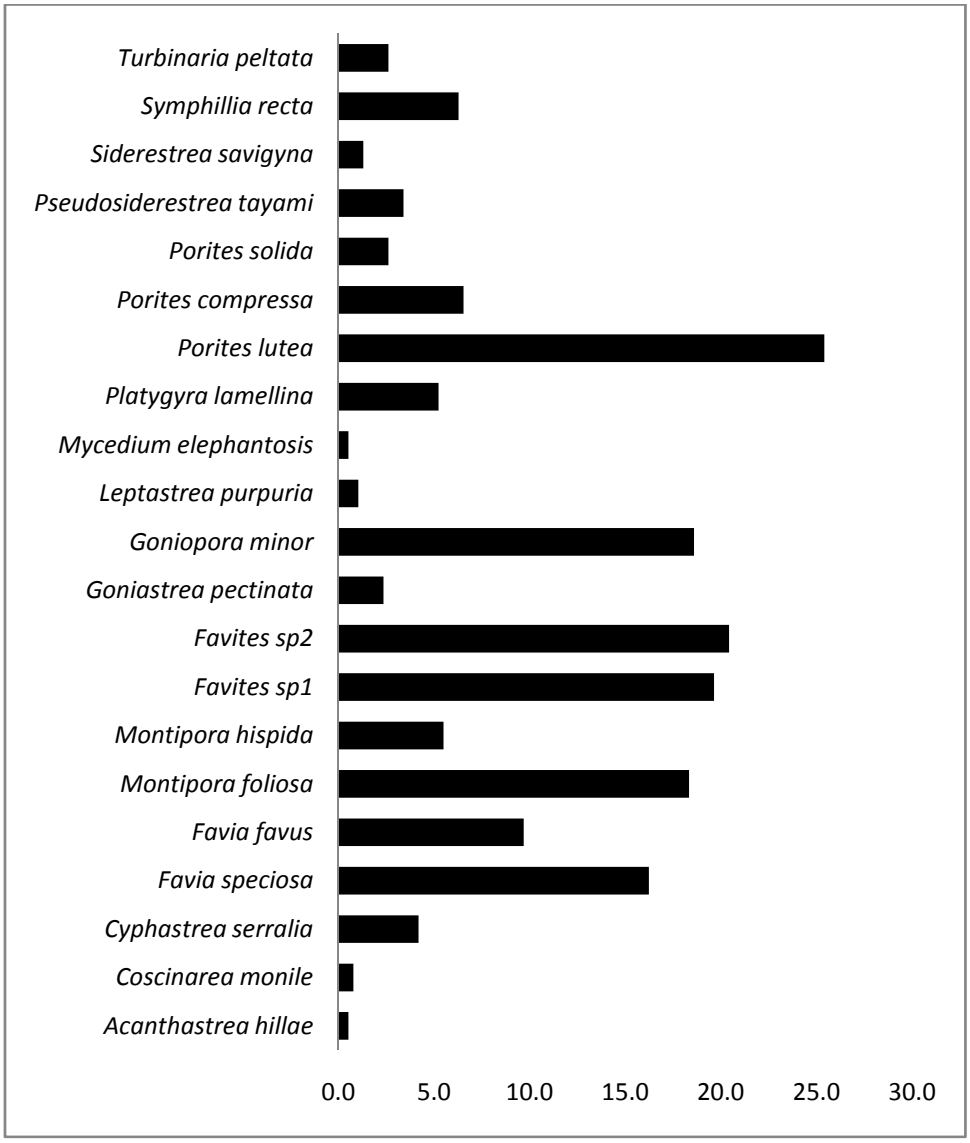
At Kalubhar *Porites lutea* was the most frequently occurring species with relative frequency of 25.4%. This was followed by two different species *Favites spp1* and *Favites spp2.* with relative frequency of 20.4% and 19.6% respectively. *Mycedium elephantosis, Coscinarea monile* and *Acanthastrea hillae* showed very low relative frequency *i.e.* below 1%.

Table 5.8: Relative Frequency of coral species (in %) at Kalubhar

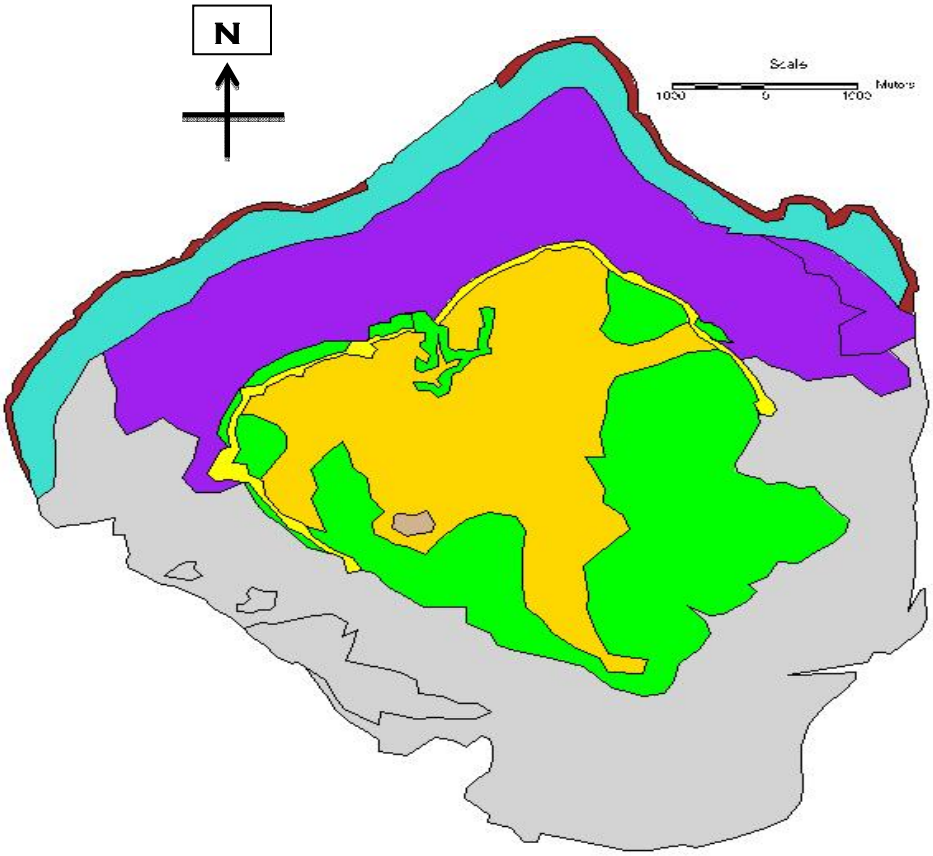
Sr. No.	Species	Relative frequency (%)
1	*Acanthastrea hillae*	0.5
2	*Coscinarea monile*	0.8
3	*Cyphastrea serralia*	4.2
4	*Favia speciosa*	16.2
5	*Favia favus*	9.7
6	*Montipora foliosa*	18.3
7	*Montipora hispida*	5.5
8	*Favites sp* 1	19.6
9	*Favites sp* 2	20.4
10	*Goniastrea pectinata*	2.4

11	*Goniopora minor*	18.6
12	*Leptastrea purpuria*	1.0
13	*Mycedium elephantosis*	0.5
14	*Platygyra lamellina*	5.2
15	*Porites lutea*	25.4
16	*Porites compressa*	6.5
17	*Porites solida*	2.6
18	*Pseudosiderestrea tayami*	3.4
19	*Siderestrea savigyna*	1.3
20	*Symphillia recta*	6.3
21	*Turbinaria peltata*	2.6

Fig: 5.8: Relative Frequency of coral species (in %) at Kalubhar



Kalubhar



Colour Code	Colour/catagory		Area (sq mtr)
1.		Algal ridge	1211905.0
2.		Outer Reef	4073422.4
3.		Inner Reef	4804775.2
4.		Sandy beach	971406.8
5.		Mangroves	11924662.8
6.		Intertidal mudflats	23175821.7
7.		Island	114877.0
8.		Reef vegetation	0
9.		High tidal mudflats	11135588.4
10.		Sandy reef	11267248.9
11.		Coral Pinnacle	0
12.		Muddy reef	0
13.		Salt Pan	0
	Total Area (Square meter) **68679708.3**		

Poshitra

Habitat Profile (Map 5.5)

Poshitra cluster has more than 16 offshore locations and two coastal locations, where coral growth has been reported. The study site is one of the coastal locations also known as Laku point. Total area of Poshitra point (Poshitra and Asaba Pir together) is 1205766.4 m^2. Here total six land cover classes were recorded. The reef area including vegetation was 830209.4 m^2, which is 68% of the total intertidal area. The intertidal area was rocky with very negligible mud deposition. There was no significant sandy beach near the high tide line. Unlike other fringing reefs, it was difficult to divide the site into reef edge reef crest and reef slope, as the area is completely unequal undulating, with shallow water tidal pools. The coral growth was observed from back water shallow tidal pools to the near shore waters. Major intertidal habitats were reef vegetation, muddy reef, sandy reef and outer reef. Heavy plantation by MNP and S authorities was observed near the back water pools.

Species Richness (Table 5.9 Fig 5.9)

Total 90% of quadrats showed presence of live corals in the upper strata, compared to 97% in the lower strata.

Within the sampled area of lower strata and upper strata, 22 species of hard corals were recorded, of which 15 were present on the upper strata and 22 were recorded from lower strata. Seven species were confined only to the lower strata, while four species *viz. Plesiastrea versipora, Parycyathus stokessi, Polycyathus verrilli and Tubastrea aurea* were recorded outside the sampled area. Hence, the total hard coral species richness of the Poshitra was 26 species. The Jaccard's species similarity index between these two strata was 0.23 only.

Table 5.9: A comparison of habitat characteristics and coral community between the upper and lower strata of the reef at Poshitra

	Parameters	Upper	Lower	Average / Total
1	Total quadrats laid	51	39	90
2	Quadrats with presence of Live Coral	46	38	84
3	Frequency of occurrence	90	97	93.8
4	Species Richness (within the sampled area)	15	22	22
5	Additional species (outside the sampled area)			4
6	Total Species Richness			26
7	Jaccard's Similarity Index			0.23
8	Benthic cover of Live corals (%)	18.7	64.5	41.6
9	Benthic cover of Algae (%)	14.4	3.6	9.0
10	Benthic cover of Mud (%)	4.3	0.0	2.1
11	Benthic cover of Sand (%)	7.8	6.3	7.1
12	Benthic cover of Rock (%)	40.2	20.5	30.4
13	Benthic cover of Rubble (%)	14.4	6.7	10.5
14	Benthic cover of Other fauna (%)			0.0
15	Probality value of t Test of Live corals between two strata			0.0016**

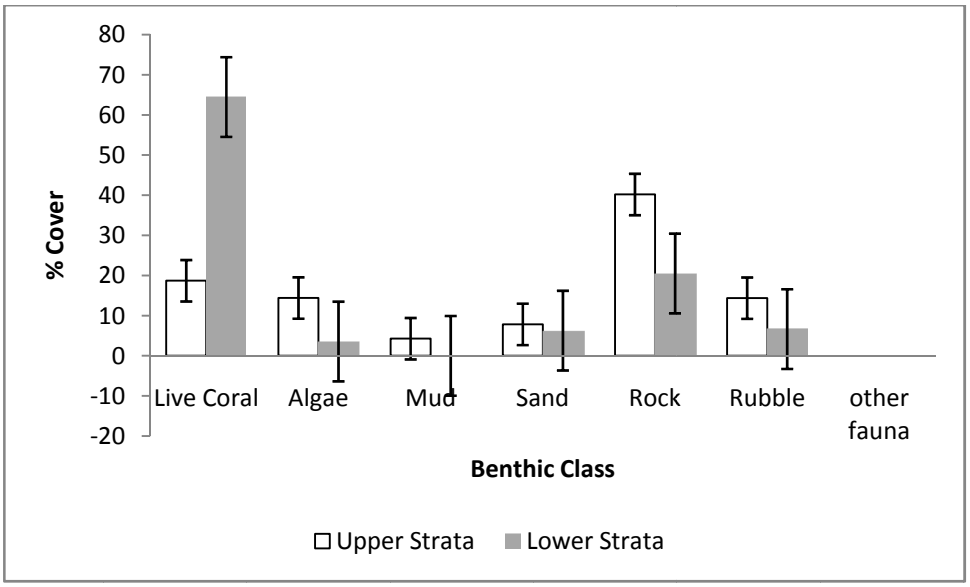
**Highly significant

Benthic Cover at Poshitra reef (Table 5.9 Fig 5.9)

Total seven parameters were considered for the benthic coverage in the quadrats for both upper and lower strata.

The average percentage of live coral cover was 41.6%. The live coral cover of lower strata (64.5%) was significantly higher than that of the upper strata (18.7%) ($P < 0.001$, $df = 89$). The most dominant substrate was rock covering 40%, followed by algae and rubble covering 14% each. Sand coverage was 7% whereas mud deposition was recorded to be 4.2%.

Fig: 5.9: Benthic Cover (% ± SEM) of upper and lower strata at Poshitra reef



Relative Frequency of Occurrence of Live corals at Poshitra reef (Table 5.10 Fig 5.10)

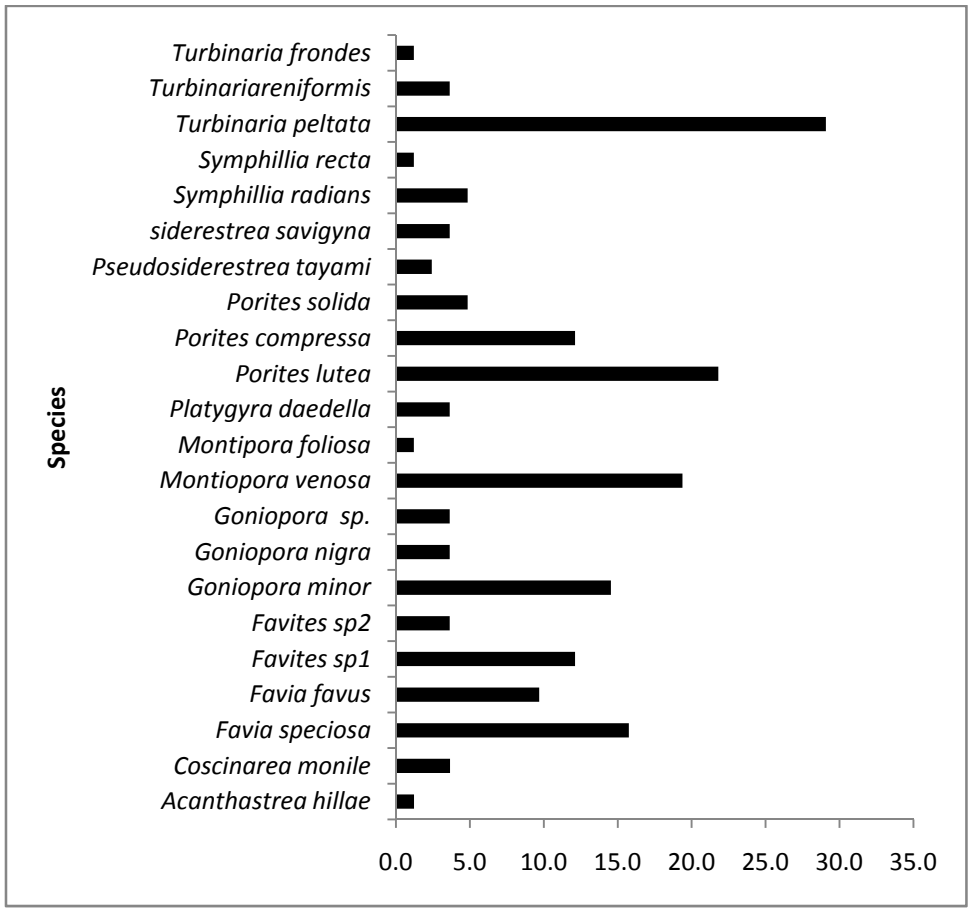
Turbinaria peltata was the most frequently occurring species with relative frequency of 29%, followed by *Porites lutea* and *Montipora venosa* with relative frequency of 22 and 19% respectively. Other species *Favia speciosa, Goniopora minor and Porites compresa* were having relative frequency of 16, 15 and 12% respectively. Four species *viz. Symphillia recta, Montipora foliosa, Turbinaria fronds* and *Acanthastrea hillae* showed very low occurrence <1%.

Table 5.10: Relative Frequency of Occurrence of coral species (in%) at Poshitra

Sr. No.	Species	Relative Frequency
1	*Acanthastrea hillae*	1.2
2	*Coscinarea monile*	3.7
3	*Favia speciosa*	15.7
4	*Favia favus*	9.7
5	*Favites sp1*	12.1
6	*Favites sp2*	3.6
7	*Goniopora minor*	14.5
8	*Goniopora nigra*	3.6
9	*Goniopora sp.*	3.6
10	*Montiopora venosa*	19.4

11	*Montipora foliosa*	1.2
12	*Platygyra daedella*	3.6
13	*Porites lutea*	21.8
14	*Porites compressa*	12.1
15	*Porites solida*	4.8
16	*Pseudosiderestrea tayami*	2.4
17	*Siderestrea savigyna*	3.6
18	*Symphillia radians*	4.8
19	*Symphillia recta*	1.2
20	*Turbinaria peltata*	29.1
21	*Turbinariareniformis*	3.6
22	*Turbinaria frondes*	1.2

Fig: 5.9: Relative Frequency of Occurrence of coral species (in%) at Poshitra reef



Asaba Pir

Habitat Profile

Asaba Pir is an offshore submerged reef. It is a part of the Poshitra cluster of reefs. The reef is inverse saucer shaped. The only intertidal habitat is coral reef. Coral growth was observed near the fringes of the reef crest in the north-west direction and north of the reef.

Due to the low benthic level from Mean Sea Water level compared to other locations of the gulf, the pools are exposed for very limited number of days during the tidal cycles. During the minus tides the reef gets exposed to a great extent and near by islands can be approached on feet.

Species Richness

At Asaba Pir total 50.43% quadrats of lower strata recorded live corals, whereas in the upper strata, 47.78% quadrats recorded live corals.

Within the sampled area 14 species of hard corals were recorded, of which 10 were present on the reef flat and all the 14 were recorded from reef slope and reef crest. Four species were confined to the reef slope and crest only. However fourteen species were recorded outside the sampled area, hence the total species richness of the location was 28 species. The Jaccard's species similarity index between these two strata was 0.71.

Table 5.11: A comparison of habitat characteristics and coral community between the upper and lower strata of the reef at Asaba Pir Reef

Sr. No.	**Parameters**	**Upper Strata**	**Lower strata**	**Total**
1	Total quadrats laid	90	115	205
2	Quadrats with presence of Live Coral	43	58	101
3	Frequency of occurrence	47.78	50.43	49.11
4	Species Richness (within the sampled area)	10	14	14
5	Additional species (outside the sampled area)			14
6	Total Species Richness			28
7	Jaccard's Similarity Index			0.71
8	Benthic cover of Live corals (%)	22	50	36
9	Benthic cover of Algae (%)	29.85	10.91	20.38
10	Benthic cover of Mud (%)	0.5	0	0.25
11	Benthic cover of Sand (%)	21.87	9.76	15.815
12	Benthic cover of Rock (%)	31.66	51.37	20
13	Benthic cover of Rubble (%)	12.41	9.24	10.825
14	Benthic cover of Other fauna (%)	0	0	0
15	Probality value of T Test of Live corals between two strata			0.0015**

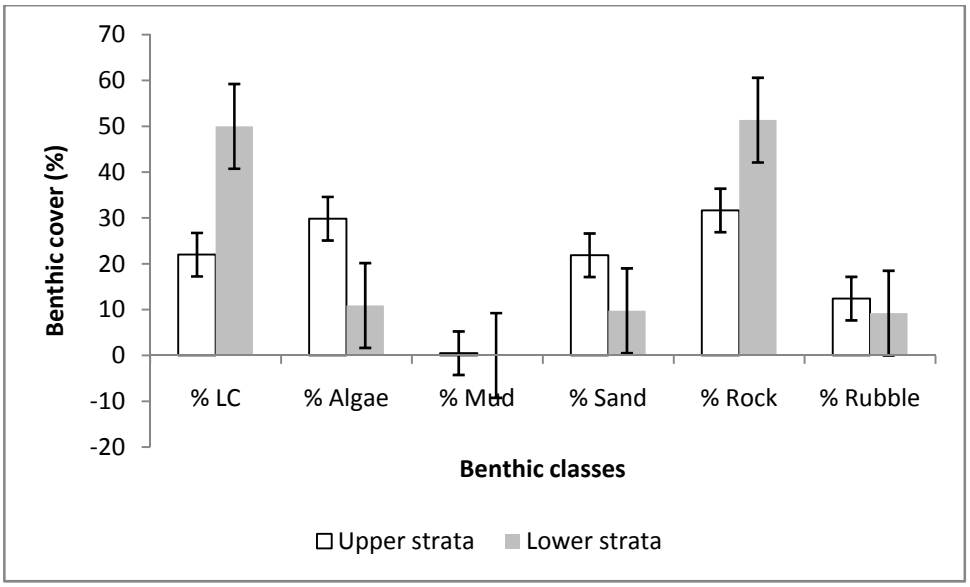
** Highly significant

Benthic Cover (Table 5.11 Fig 5.11)

Seven Parameters were considered for the benthic coverage in the quadrats for both upper and lower strata.

Total percentage of live coral cover of lower strata (50%) was significantly high than the upper strata (22%) ($P<0.001$, $df = 204$). The most dominant substrate was rock with 50% cover in the lower strata and 31.66% in the upper strata. Algal cover was 10.91% in the lower strata and 29.85% in the upper strata, sand coverage was 21.87% in the upper strata compared to 9.76% in the lower strata, while rubble coverage was 12.41% in the upper strata compared to 9.24% in the lower strata.

Fig: 5.12: % Benthic Cover at Asaba Pir in upper and lower strata



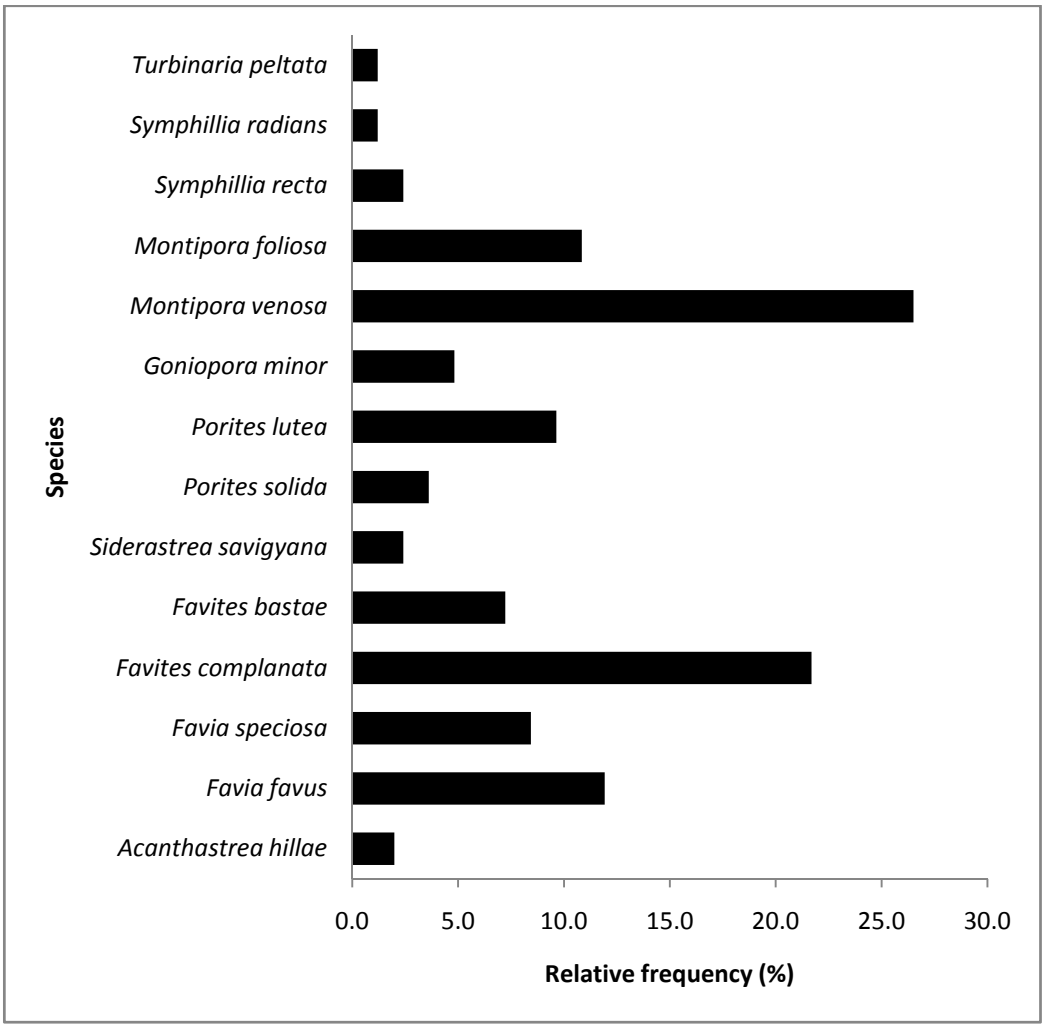
Relative Frequency of hard corals at Asaba Pir (Table 5.12 Fig 5.12)

Montipora venosa, *Favites complanata* and *Favia favus* were found to be frequently occurring species with relative frequency of 23, 19 and 12% respectively. These were followed by *Montipora foliosa*, *Porites lutea and Favia speciosa* with relative frequency of 9, 8 and 7% respectively. Two species viz. *Turbinaria peltata* and *Symphillia radians* showed very low occurrence.

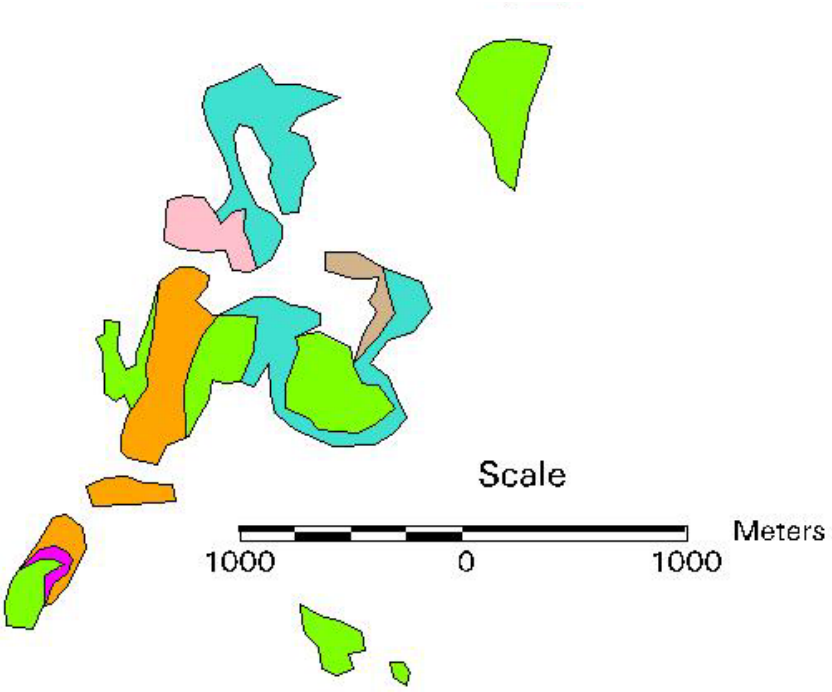
Table 5.12 Relative Frequency of Occurrence of coral species (in%) at Asaba Pir

Sr. No.	Species	Relative frequency
1	*Acanthastrea hillae*	2.0
2	*Favia favus*	11.9
3	*Favia speciosa*	8.4
4	*Favites complanata*	21.7
5	*Favites bastae*	7.2
6	*Siderastrea savigyana*	2.4
7	*Porites solida*	3.6
8	*Porites lutea*	9.6
9	*Goniopora minor*	4.8
10	*Montipora venosa*	26.5
11	*Montipora foliosa*	10.8
12	*Symphillia recta*	2.4
13	*Symphillia radians*	1.2
14	*Turbinaria peltata*	1.2

fig: 5.12: Relative Frequency of Occurrence of coral species (in%) at Asaba Pir



Poshitra and AsabaPir



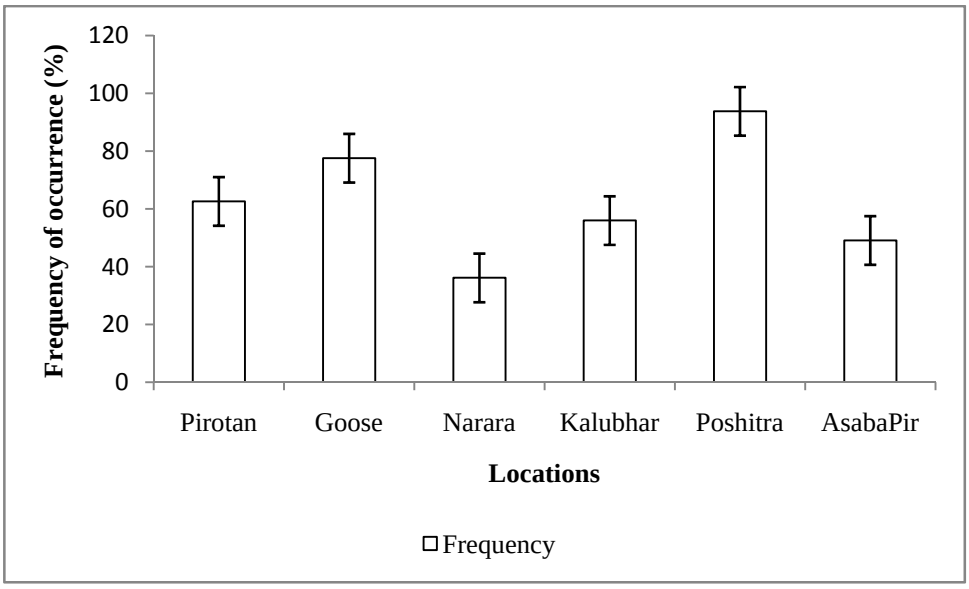
Colour Code	Colour/catagory		Area (sq mtr)
1.		Algal ridge	0
2.		Outer Reef	476504
3.		Inner Reef	0
4.		Sandy beach	0
5.		Mangroves	0
6.		Intertidal mudflats	89265.0
7.		Island	286290.8
8.		Reef vegetation	281487.7
9.		High tidal mudflats	0
10.		Sandy reef	20166
11.		Coral Pinnacle	0
12.		Muddy reef	52051.7
13.		Salt Pan	0
	Total Area (Square meter)		**1205766.4**

COMPARITIVE ANALYSIS OF SIX STUDY LOCATION

Sampling area and frequency of occurrence (Fig: 5.13)

In the study area altogether 62% quadrats showed occurrence of live corals. Poshitra showed highest frequency of live corals (98%), followed by Goose reef (78%), whereas lowest frequency of occurrence was encountered at Narara coastal reef (36%).

Fig: 5.13: Frequency of occerence of live corals at six study locations



Species Richness (Fig 5.14, Table 5.14)

The scleractinian species richness in the study area was 38 species belonging to 20 genera. *Favites* and *Porites* contributed maximum 4 species each in the total species richness while 11 genera contributed single species each with other contributing 3 or 2 species. Maximum species *i.e.* 28 were recorded at Asaba Pir the western most reef, whereas minimum 18 species at Goose reef. Nine species *viz. Acanthastrea hillae, Favia speciosa, Favia favus, Goniopora minor, Porites lutea, Siderestrea savigyna, Pseudosiderastrea tayami, Symphilia recta* and *Parycyathus stokessi* were recorded from all six locations with good frequeny of occurrence. Whereas seven species *viz. Favites complanata, Montipora hispida, Platygyra sinensis, Porites hispida, Turbinaria frondes, Polycyathus verrilli* and *Barabattoia amicorum* were confined to any single location and

that also with very low frequency of occurrence. Five species *Platygyra daedella, Plesiastrea verscipora, Symphillia radians, Turbinaria reniformes* and *Tubastrea aurea* were confined to Poshitra and Asaba Pir only. With *Turbinaria frondes* and *Polycyathus verrili* recorded only from Poshitra and *Barabattoia amicorum* recorded only from Asaba Pir.

Similarity Index (Table 5.13)

When Jaccard's species similarity index was performed, similarities between the eastern and centrally located reefs *viz.* Pirotan, Goose, Narara and Kalubhar showed greater similarities, and western locations, *viz.* Poshitra and Asaba Pir showed greater similarity between the two. Goose and Kalubhar showed maximum similarity in the species richness (J = 0.78), followed by Poshitra and Asaba Pir (J =0.69). Lowest similarity was recorded between Narara and Asaba Pir (J = 0.41) and between Poshitra and Goose (J = 0.42).

Table 5.13: Jaccard's species similarity index

Locations	**Pirotan**	**Goose**	**Narara**	**Kalubhar**	**Poshitra**	**Asaba Pir**
Pirotan	1	0.6	0.63	0.62	0.50	0.47
Goose		1	0.58	0.78	0.42	0.44
Narara			1	0.65	0.48	0.41
Kalubhar				1	0.48	0.5
Poshitra					1	0.69
Asaba Pir						1

Fig: 5.14: Contribution of genera in the species richness recorded during the study

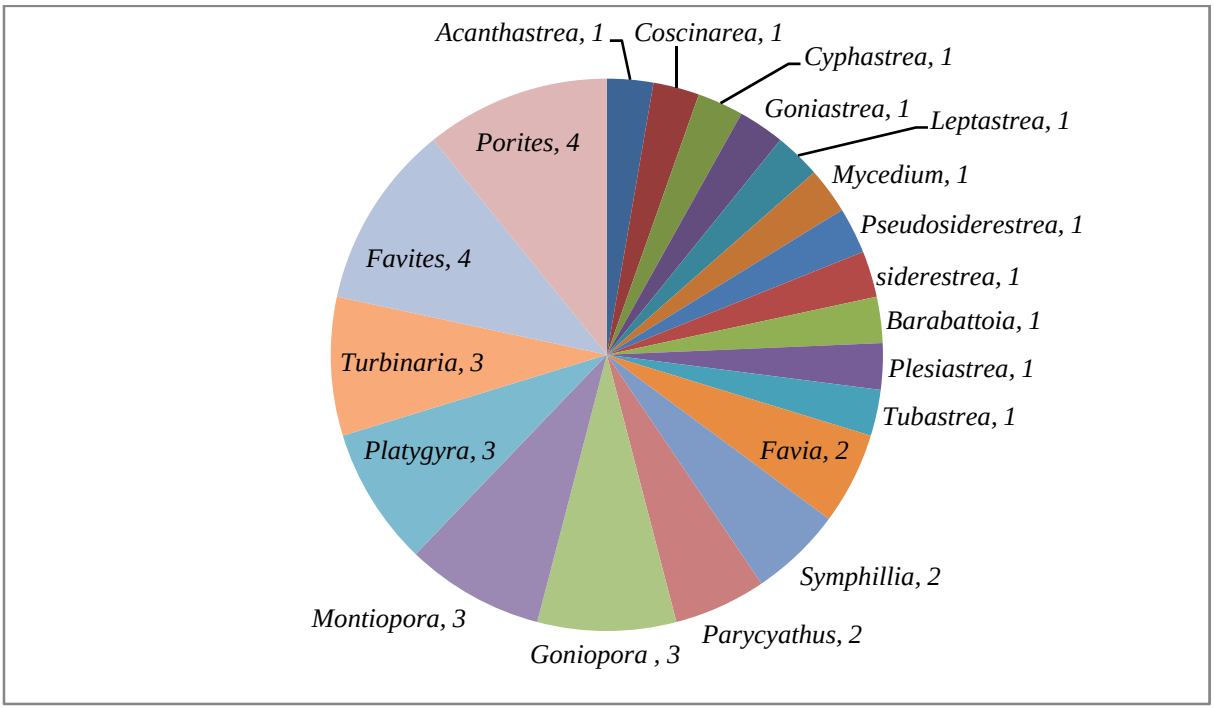


Fig: 5.15: Species Richness of hard corals at six study locations

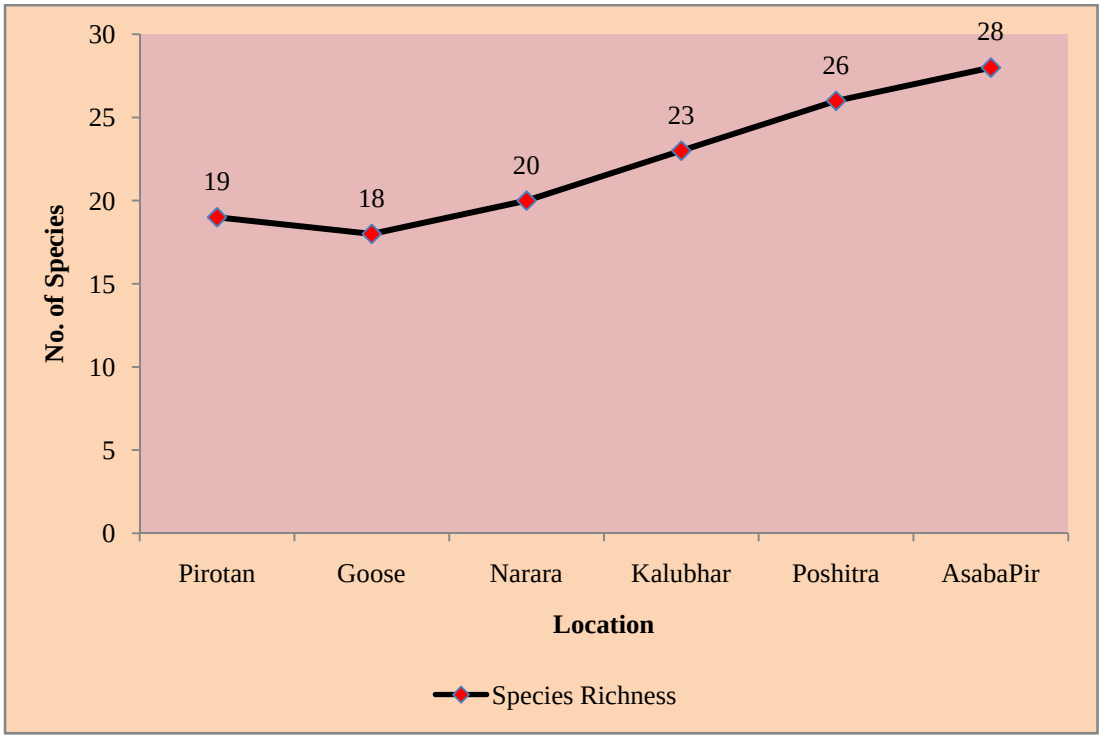


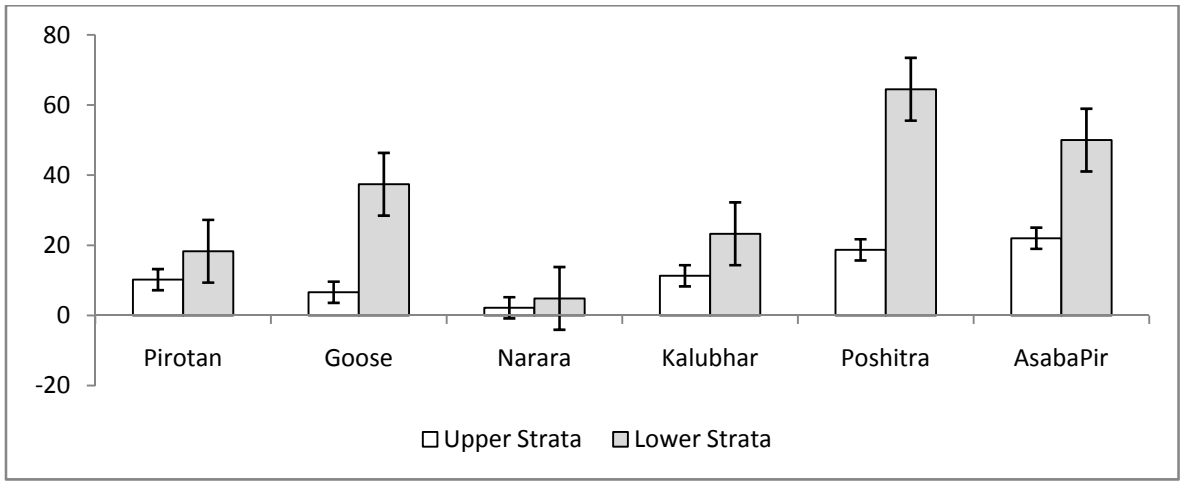
Table: 5.14: Species Richness of hard corals at study locations (Plate 5.1, 5.2, 5.3, 5.4)

Sr. no.	Species	Pirotan	Goose	Narara	Kalubhar	Poshitra	Asaba Pir
1	*Acanthastrea hillae*	*	*	*	*	*	*
2	*Coscinarea monile*	*	*	-	*	*	*
3	*Cyphastrea seralia*	*	*	*	*	-	*
4	*Favia speciosa*	*	*	*	*	*	*
5	*Favia pallida*	-	-	-	*	-	*
6	*Favia favus*	*	*	*	*	*	*
7	*Favites sp1.*	*	*	*	*	*	-
8	*Favites sp2.*	*	-	*	*	*	-
9	*Favites complanata*	-	-	-	-	-	*
10	*Favites bastae*	*	-	-	-	-	*
11	*Goniopora minor*	*	*	*	*	*	*
12	*Goniopora nigra*	*	-	-	-	*	*
13	*Goniopora sp.*	-	-	-	-	*	*
14	*Goniastrea pectinata*	-	*	*	*	-	-
15	*Leptastrea purpuria*	*	*	*	*	-	-
16	*Montiopora venosa*	*	-	*	-	*	*
17	*Montipora foliosa*	-	*	*	*	*	*
18	*Montipora hispida*	-	-	-	*	-	-
19	*Mycedium elephantosis*	-	*	-	*	-	*
20	*Platygyra daedella*	-	-	-	-	*	*
21	*Platygyra lamelina*	*	*	-	*	-	-
22	*Platygyra sinensis*	-	-	*	-	-	-
23	*Porites lutea*	*	*	*	*	*	*
24	*Porites compressa*	-	*	-	*	*	*
25	*Porites solida*	*	-	*	*	*	*
26	*Porites hipsida*	-	-	*	-	-	-
27	*Pseudosiderestrea tayami*	*	*	*	*	*	*
28	*Plesiastrea versipora*	-	-	-	-	*	*
29	*Siderestrea savigyna*	*	*	*	*	*	*
30	*Symphillia radians*	-	-	-	-	*	*
31	*Symphillia recta*	*	*	*	*	*	*
32	*Turbinaria peltata*	-	-	*	*	*	*
33	*Turbinaria reniformis*	-	-	-	-	*	*
34	*Turbinaria frondes*	-	-	-	-	*	-
35	*Parycyathus stokessi*	*	*	*	*	*	*
36	*Polycyathus verrilli*	-	-	-	-	*	-
37	*Tubastrea aurea*	-	-	-	-	*	*
38	*Barabattoia amicorum*	-	-	-	-	-	*
	Total	**19**	**18**	**20**	**23**	**26**	**28**

Comparitive analysis of Live coral cover of Upper strata and Lower strata

The live coral cover of the upper strata of all six locations and the live coral cover of the lower strata of all six locations were compared and they showed significant difference. Hence, the mean percent area of live coral cover of upper strata of six study locations was 11.83% (SD ±7.40), significantly lower than the mean live coral cover of lower strata (33% SD± 21.9) ($P < 0.001$, df = 1970). The difference between two strata with reference to live coral cover were maximum at Poshitra followed by Asaba Pir and Goose and minimum at Narara. Hence, further analysis of Live Corals was restricted to the lower strata only.

Fig: 5. 16: Live coral cover (%) of both the strata at six locations in the MNP and S

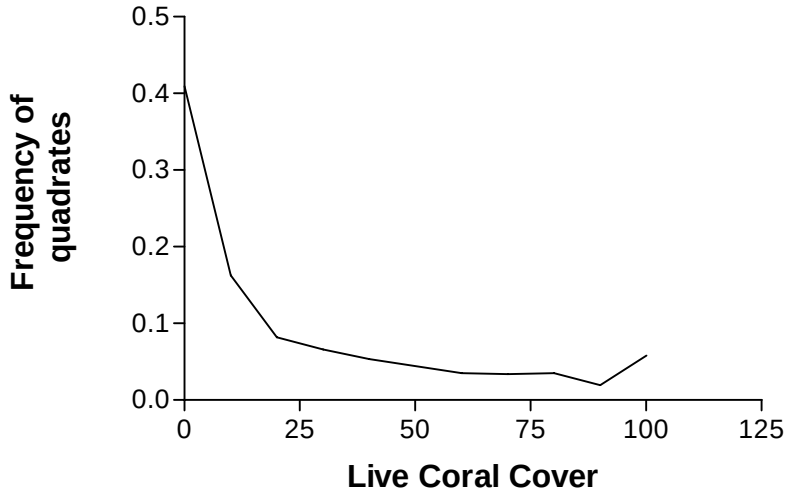


Frequency distribution graph (Fig. 5.17) showed that 40% quadrats were having no live coral cover, 16% were having 1 to 10% live coral cover, whereas only 5% were having coral cover between 90 to 100%.

Table 5.15: Frequency Distribution table of live coral cover of six locations in MNP and S

Quadrate with Live coral cover (n)	Lower Strata Frequency (f)	Frequency (%) (=f*100)
0	0.40	40
1-10	0.16	16
10-20	0.08	08
20-30	0.06	06
30-40	0.05	05
40-50	0.04	04
50-60	0.03	03
60-70	0.03	03
70-80	0.03	03
80-90	0.01	01
90-100	0.05	05

Fig: 5.17 Frequency distribution graph of live coral cover of lower strata



One way Analysis of Variance (ANOVA) was performed followed by Bonferroni's Multiple comparison test for the live coral cover of the lower strata of six study locations. The result revealed that, there is a significant difference of coral cover (P<0.0001, df = 878) between Pirotan, Goose and Narara, whereas there was no significant difference in live coral cover between Goose and Asaba Pir, Pirotan and Kalubhar and Poshitra and Asaba Pir. This non significant difference may be attributed to the geo-morphology of the area, as Goose and Asaba Pir both are submerged reefs and Pirotan and Kalubhar both are islands with fringing reefs.

Table 5.16: One way Analysis Of Variance (ANOVA) for live coral cover (%)

Table Analyzed	Lower Strata		Bonferroni
Data Table			
One-way analysis of variance			
P value	P<0.0001		
P value summary	***		
Are means significantly different ? (P < 0.05)	Yes		
Number of groups	6		
F	45.61		
R squared	0.2071		
Bartlett's test for equal variances			
Bartlett's statistic (corrected)	195.6		
P value	P<0.0001		
P value summary	***		
Do the variances differ significantly ? (P < 0.05)	Yes		
ANOVA Table	SS	df	MS
Treatment (between columns)	175700	5	35130
Residual (within columns)	672500	873	770.3
Total	848200	878	

Table 5.17 Bonferroni Multiple comparison Test for six study locations for live coral cover (%)

Bonferroni's Multiple Comparison Test	Mean Diff.	t	P value	95% CI of diff
Pirotan vs Goose	-19.07	5.924	P < 0.001	-28.55 to -9.596
Pirotan vs Narara	13.45	4.437	P < 0.001	4.526 to 22.37
Pirotan vs Kalubhar	-4.976	1.867	P > 0.05	-12.82 to 2.870
Pirotan vs Poshitra	-46.18	9.323	P < 0.001	-60.76 to -31.60
Pirotan vs Asaba Pir	-28.46	5.433	P < 0.001	-43.88 to -13.04
Goose vs Narara	32.52	10.29	P < 0.001	23.22 to 41.82
Goose vs Kalubhar	14.1	5.015	P < 0.001	5.823 to 22.37
Goose vs Poshitra	-27.11	5.386	P < 0.001	-41.93 to -12.30
Goose vs Asaba Pir	-9.388	1.767	P > 0.05	-25.03 to 6.253
Narara vs Kalubhar	-18.42	7.106	P < 0.001	-26.05 to -10.79
Narara vs Poshitra	-59.63	12.13	P < 0.001	-74.10 to -45.16
Narara vs Asaba Pir	-41.91	8.056	P < 0.001	-57.22 to -26.60
Kalubhar vs Poshitra	-41.21	8.771	P < 0.001	-55.04 to -27.38
Kalubhar vs Asaba Pir	-23.48	4.699	P < 0.001	-38.19 to -8.775
Poshitra vs Asaba Pir	17.72	2.721	P > 0.05	-1.445 to 36.89

Benthic Cover (Fig 5.18 to Fig 5.23)

Among various benthic parameters, mud deposition was significantly high on the reef of Goose with 26.8% coverage, deposition of sand recorded at all the six locations, which ranged from 7% to 19% with maximum 19% coverage at Pirotan. Coverage of Rock was maximum at Narara (38.5%), followed by Poshitra (30.4%) and Pirotan (29.4%). Maximum rubbles were recorded at Goose (14.3%) and Narara (12.75%), while minimum at Kalubhar (4%). The coverage associated fauna is depicted in % coverage of the sampling area i.e. quadrats. The % occupancy of associated faua is calculated based on the coverage of the organism in the quadrat. Maximum coverage of associated sedentary fauna though low, was recorded at Goose (2.70%) and Narara (1.0%). Whereas it was almost absent at Poshitra and Asaba Pir. The species recorded were *Polythoa spp*. and *Stichodactyla haddoni*,

Table 5.18: Average benthic cover (%) at six study locations

Benthic Cover class	Pirotan	Goose	Narara	Kalubhar	Poshitra	Asaba Pir
% Live Coral	14.3	22	3.51	17.3	41.6	36
% Algae	28.3	7.9	31.625	46.24	9	20.38
% Mud	0.8	26.8	2.85	0.76	2.1	0.25
% Sand	18.9	13.3	9.7	10.09	7.1	15.815
% Rock	29.3	12.9	38.5	21.17	30.4	20
% Rubble	7.8	14.3	12.75	4.21	10.5	10.825
% Other Fauna	0.5	2.7	1.015	0.24	0	0

Fig: 5.18 Coverage of Mud at six study locations

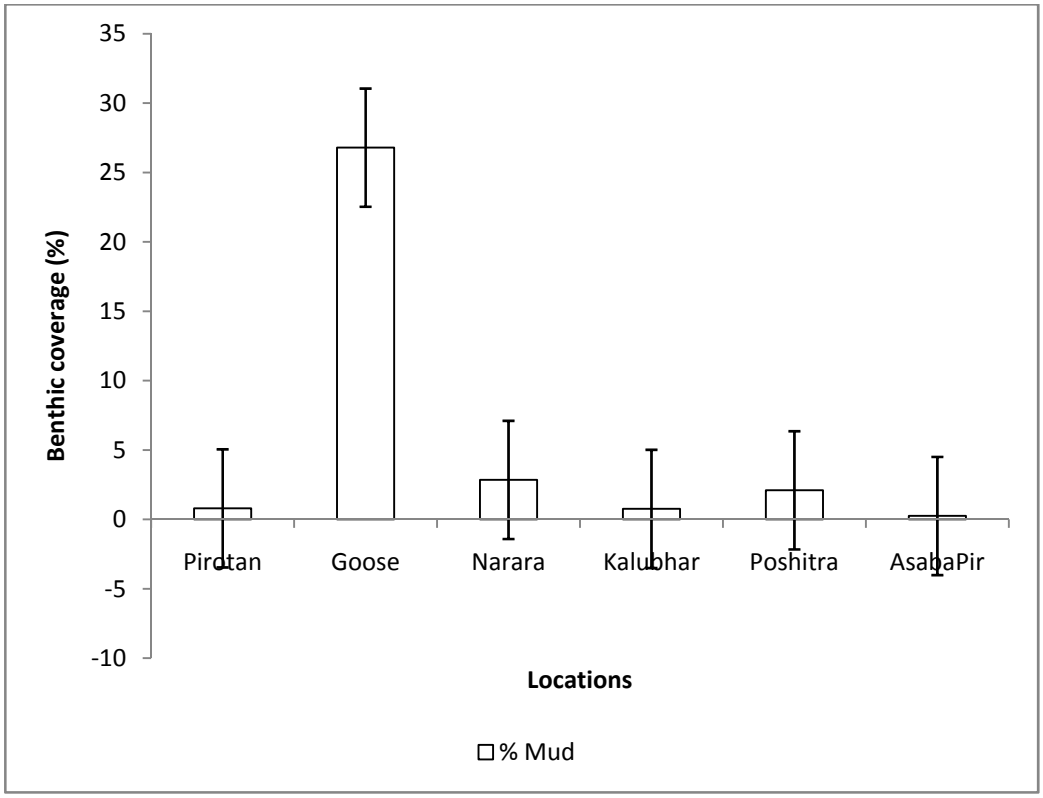


Fig: 5.19: Coverage of Sand (%) at six study locations

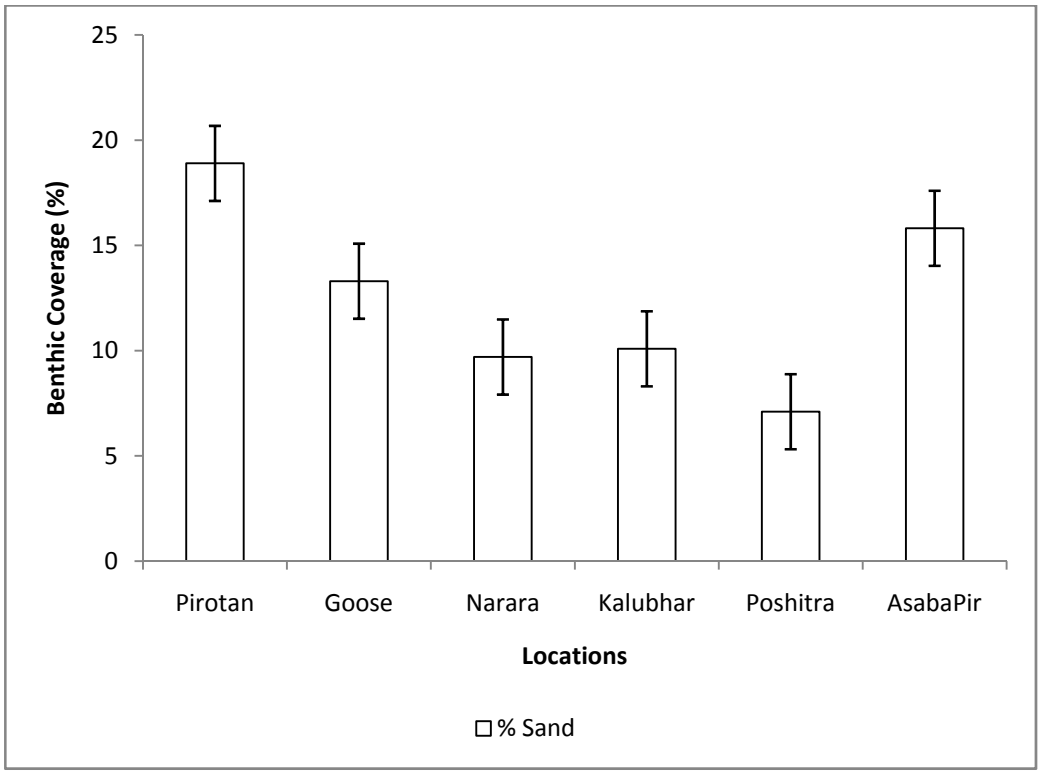


Fig: 5.20 Coverage of Algae (%) at six study locations

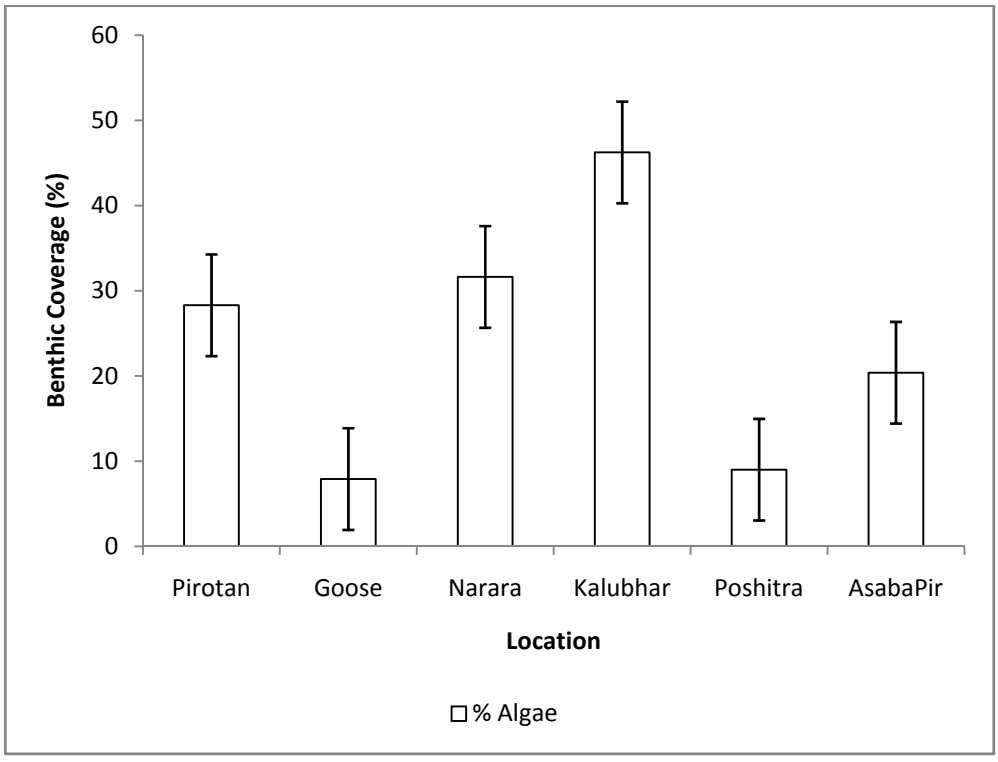


Fig: 5.21: Coverage of Rubbles (%) at six study locations

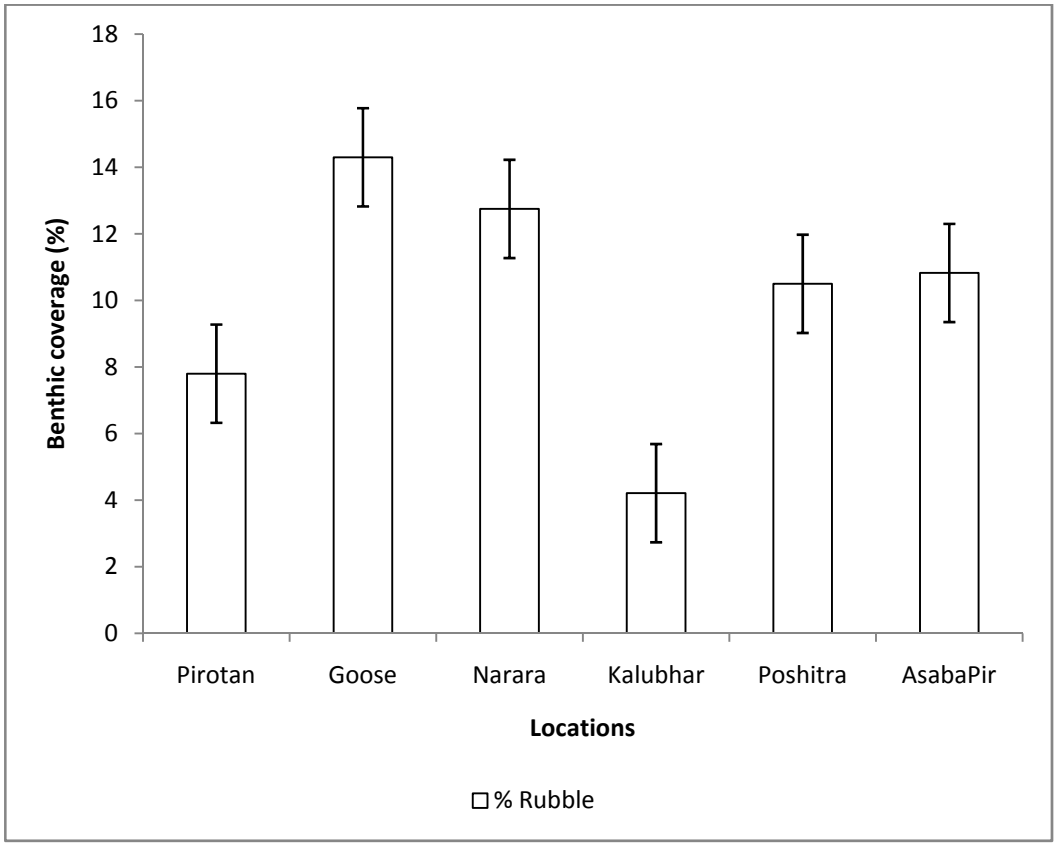


Fig: 5.22: Coverage of Rocks (%) at six study locations

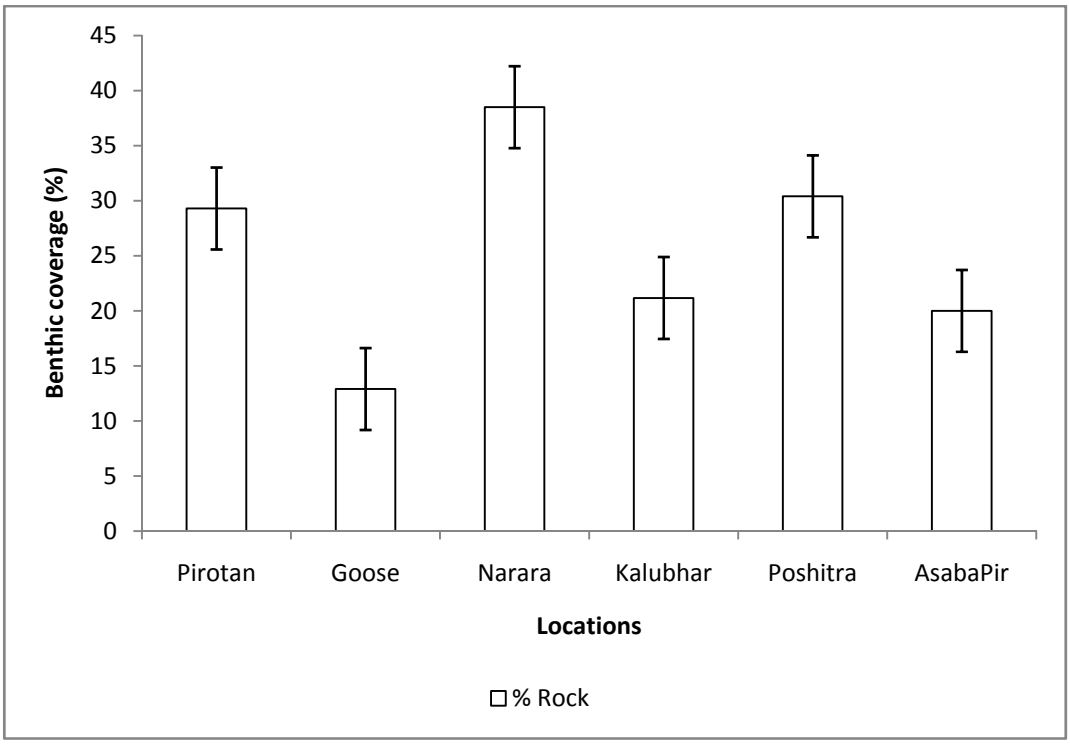


Fig 5.23: Coverage of Other Fauna at six locations

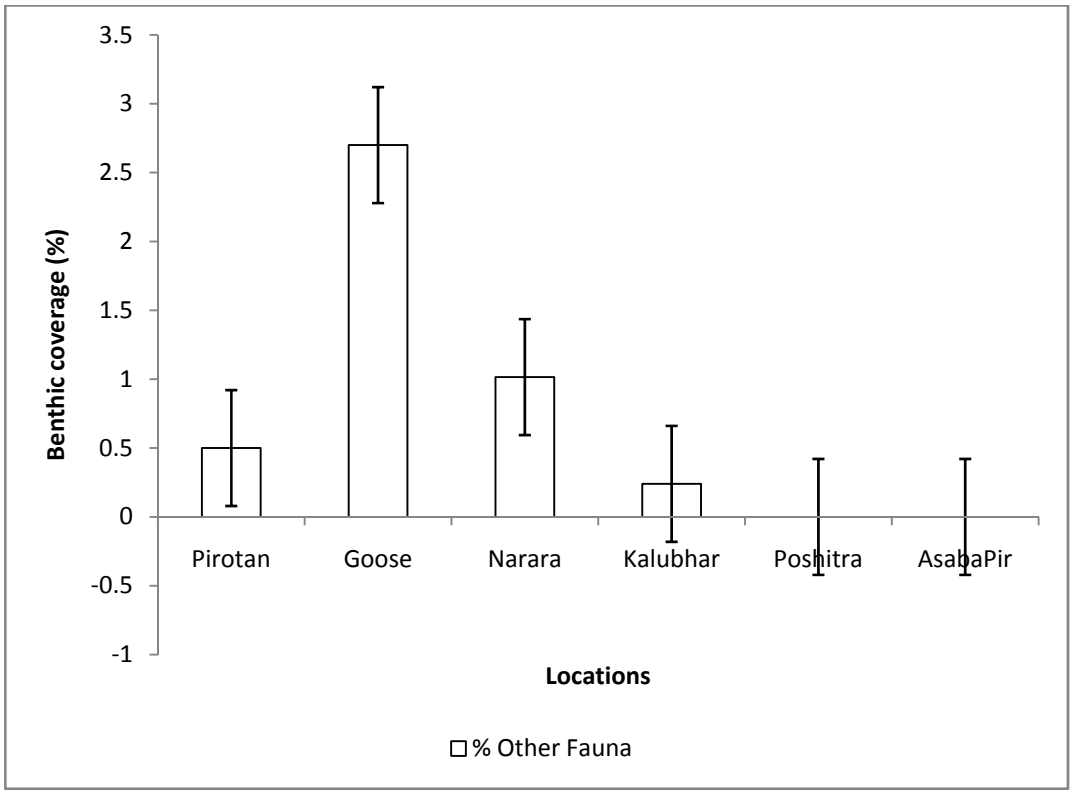


Table: 5.19: A comparison of reef classes of GoK studied by DOD and SAC (1997) and current study.

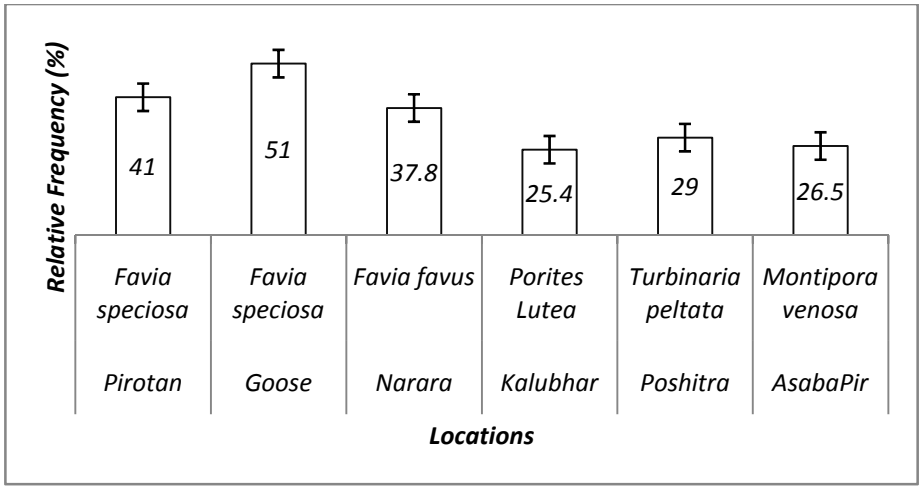
		DOD and SAC 1997, (Gulf of Kachchh)		Current Study (Six representative reefs)	
Sr. No.	**Major reef classes**	**Area (km^2)**	**occupancy (%)**	**Area (km^2)**	**occupancy (%)**
1	Upper strata	148.4	33	21.1	30.6
2	Sandy reef	11.8	2	16.3	23.7
3	Muddy reef	117.1	26	1.9	2.7
4	Lower strata	Not Mentioned		20.6	30
5	Other classes	182.7	39	8.9	13
	Total	460		68.8	

Comparitive analysis was carried out for the area estimation, between the DOD and SAC (1997) study and the current study. However, the earlier was carried out for the whole Gulf of Kachchh, whereas the latter was confined to only six representative sites,

maximum area (%) was covered by the upper strata in the reef ecosystem, followed by lower strata in the current study.

Maximum relative abundance was recorded of *Favia speciosa* with 41% at Pirotan and 51% at Goose, the other species of *Favia* genus *viz. F. favus* was dominant at Narara with 37.8%. However at Kalubhar, *Porites lutea* recorde 25.4% and at Poshitra and Asaba Pir maximum frequency was recorded for *Turbinaria peltata* (29%) and *Montipora venosa* (26.5%)

Fig: 5.24: Relative frequency (%) of most dominant scleractinian corals at six sites



A comparison between the checklist of Pillai and Patel (1988) and the current study for the four (as there are only four common sites between the two studies in the eastern and central gulf area reveals that total 13 species are such which were recorded earlier by Pillai and Patel (1988), are not recorded in the study even with an extensive effort (Table 5.19). All the 13 species have abolished from Pirotan, whereas from Goose, Narara and Kalubhar 6, 1 and 3 species respectively could not be recorded.

Table: 5.20: Comparison of Species Richness of four study locations between Pillai and Patel (1988) and Current study (Characterise the species)

Sr. No.	Scientific Name	IUCN Status	**Pi**	**1**	**G**	**1**	**N**	**1**	**K**	**1**
1	*Acanthastrea hillae*	NT	*	*	*	-	*	-	*	-
2	*Coscinarea monile*	LC	*	*	*	-	-	-	*	-
3	*Cyphastrea seralia*	LC	*	*	*	*	*	*	*	-
4	*Favia speciosa*	LC	*	*	*	-	*	-	*	-
5	*Favia pallid*	LC	-	-	-	-	-	-	*	-
6	*Favia favus*	LC	*	*	*	*	*	*	*	*
7	*Favites sp1.*		*	-	*	-	*	-	*	-
8	*Favites sp2.*		*	-	-	-	*	-	*	-
9	*Favites complanata*	NT	-	*	-	*	-	-	-	-
10	*Favites melicerum*	DD	-	*	-	*	-	-	-	-
11	*Favites bastae*	NT	*	-	-	-	-	-	-	-
12	*Goniopora minor*	NT	*	*	*	-	*	-	*	-
13	*Goniopora nigra*	DD	*	*	-	-	-	-	-	-
14	*Goniopora planulata*	VU	-	*	-	-	-	-	-	*
15	*Goniopora sp.*		-	-	-	-	-	-	-	-
16	*Goniastrea pectinata*	LC	-	*	*	*	*	*	*	-
17	*Hydnophora exesa*	NT	-	*	-	-	-	-	-	-
18	*Leptastrea purpuria*	LC	*	-	*	-	*	-	*	-
19	*Montiopora venosa*	NT	*	-	-	-	*	-	-	-
20	*Montipora explanata*	DD	-	*	-	*	-	*	-	*
21	*Montipora foliosa*	NT	-	-	*	-	*	-	*	-
22	*Montipora hispida*	LC	-	*	-	-	-	-	*	-
23	*Mycedium elephantosis*	LC	-	-	*	-	-	-	*	-
24	*Platygyra daedella*	LC	-	-	-	-	-	-	-	-
25	*Platygyra lamelina*	NT	*	-	*	-	-	-	*	-
26	*Platygyra sinensis*	LC	-	*	-	*	*	-	-	-
27	*Porites lutea*	LC	*	*	*	-	*	-	*	*
28	*Porites compressa*	LC	-	*	*	-	-	-	*	-
29	*Porites solida*	LC	*	-	-	-	*	-	*	-
30	*Porites lichen*	LC	-	*	-	*	-	-	-	*
31	*Porites hipsida*	LC	-	-	-	-	*	-	-	-
32	*Pseudosiderestrea tayami*	NT	*	*	*	*	*	*	*	*
33	*Plesiastrea versipora*	LC	-	-	-	-	-	-	-	-
34	*Siderestrea savigyna*	LC	*	-	*	-	*	-	*	-
35	*Symphillia radians*	LC	-	-	-	-	-	-	-	-
36	*Symphillia recta*	LC	*	-	*	-	*	-	*	-
37	*Turbinaria peltata*	VU	-	*	-	*	*	*	*	-
38	*Turbinaria reniformis*	VU	-	*	-	-	-	-	-	-
39	*Turbinaria fronds*	LC	-	-	-	-	-	-	-	-
40	*Paracyathus stockessi*	DD	*	*	*	-	*	-	*	-

41	*Polycyathus verrilli*	DD	-	*	-	-	-	-	-	-
42	*Tubastrea aurea*	DD	-	-	-	-	-	-	-	-
43	*Barabattoia amicorum*	LC	-	-	-	-	-	-	-	-
	Present in Pillai and absent in current study		13		6		1		3	
	Present in current study absent in Pillai's study		9		14		15		20	
	Present in both studies		10		4		5		3	

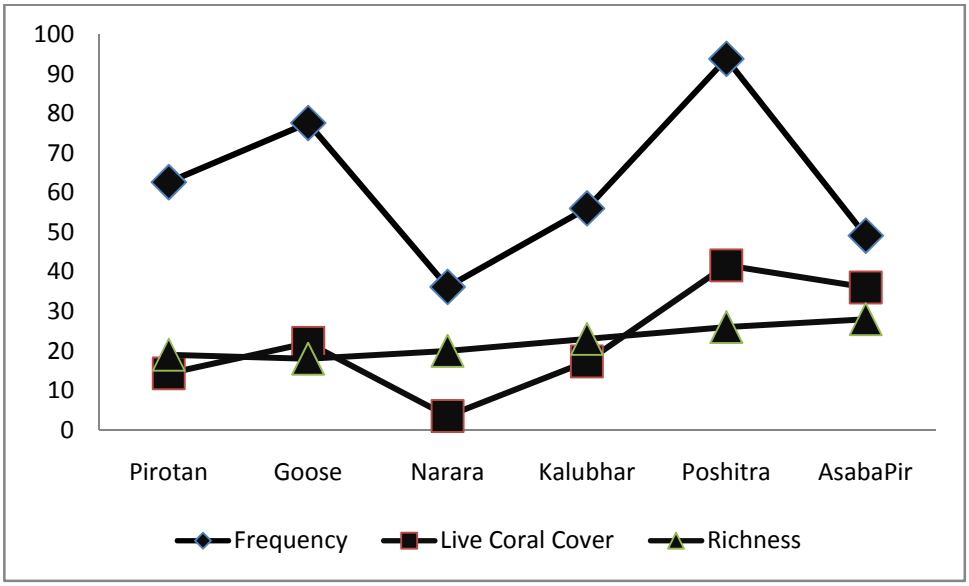
1 = Pillai and Patel (1988), Pi = Pirotan, G = Goose, N = Narara, K = Kalubhar

Table: 5.21: Pearson correlation between Species richness, Frequency of occurrence and Live coral cover

	Richness	Frequency	Live coral cover (%)
Richness	1	0.07	0.75
Frequency		1	0.64
Live coral cover (%)			1

From Pearson correlation index (Fig 5.25 Table 5.21) it was evident that the variations in the live coral cover is corresponding with the frequency of occurrence of live corals and the species richness of live corals and vice versa.

Fig: 5.25 Relationship between Species Richness, Frequency and Live coral cover



Bleaching event 2010 (Table 5.21)

During the field visit of October 2010 with GEER Foundation, considerable bleaching (approximately 90% corals were bleached) was observed at Poshitra. Subsequently in December 2010, 55% recovery was observed and by March 2011 complete recovery was observed. No mortality was recorded due to this bleaching.

Table: 5.22: Bleaching event recorded during the study at Poshitra

Sr. No.	Visit Month	Bleaching recorded (%)	Major Genera bleached	% recovery
1	October 2010	90	*Porites, Turbinaria, Symphillia, Favia*	0
2	December 2010	50	*Porites, Favia*	55
3	March	0	--	100

5.3 DISCUSSION

Among the four major coral reefs of India, the reefs of Andaman and Nicobar, Lakshadweep and Gulf of Mannar are studied extensively and hence their status is known. However comparatively very little attention had been paid to to the corals of GoK and hence, though it is one of the four major coral reefs of India, the current status of the coral present here is poorly known. However, all the scleractinian taxa of India including that of Gulf of Kachchh have been categorised under schedule I of the Wildlife Protection Act – 1972 by Government of India.

The coral ecosystem is one of the most threatened ecosystem in the world (Pillai, 2010). Of the total 154 km^2 area covered under six study sites, the reef area was 68.8 km^2, with 20.5 km^2 (33% of the reef area) area of lower strata and remaining 48.2 km^2 of upper strata. Of these 48.2 km^2 sand and 11 km^2 *i.e.* (26.4 %) mud cover in the upper strata indicate the level of threat. Deposition of such sedimentary material may create stress to corals, ultimately leading to their mortality (Patel, 1978; Ayling and Ayling, 1995; Berkelmans and Oliver, 2009). As per DOD and SAC (1997) reports of the total reef area of GoK *i.e.* 460 km^2, 11.8 km^2 reef area is under sand cover. (in the current study it has been identified as sandy reefs) and 117 km^2 as covered with mud (in the current study it has been refered as muddy reefs). These are the critical habitats of the reef undergoing degradation process due to sedimentation.

Looking at the habitat profile, 26.4% of the reef in the upper strata covered with sand and mud deposition reflects the probable restriction of coral growth in the upper strata due to sand and mud deposition as is supported by low coral species richness and poor live coral cover (Table 5.18). In addition due to easy access, in upper strata, the anthropogenic activities are also high threatening live corals. The low deposition of sand and mud on lower strata can be attributed to the continuous flushing of water due to wave

action and lesser anthropogenic disturbance due to very limited exposure period, leading to less accessibility to the area. Majority of healthy coral growth was observed in the lower strata (Average Live coral cover 33%) of the reef, which occupied only 30% of the total reef area studied.

If the vegetation dominates over reef it is considered as a threat to corals. In GoK algae remained on the reefs from November to April (Pandey, 2010). For algal growth in the area, nutrients and the drainage system of the nearby area is important and needs to be investigated thoroughly. The algal cover differed around reef with minimum 7.9% at Goose to 46% at Kalubhar. This indicates that the nutrient input around each reef is different with different drainage system on the nearest mainland. The vegetation cover is also found to be higher in upper strata of reef on the six reefs studied. However at the most disturbed site Narara, the vegetation cover was found to be higher in lower strata also. Hence, these parameters in GoK may have produced some damage in the nutrient favouring algal growth not only in the upper strata but also in the lower strata. Looking at the habitat profile it can be said that reefs of GoK are always facing the threat due to sand, mud and vegetation cover and needs to be controlled.

Species Richness:

Though several scientists have worked on coral taxa in GoK, the information available on their distribution is patchy (Hornell, 1909; Patel, 1978; Pillai and Patel, 1988; Deshmukhe *et al.* 2000; Venkatraman, 2003; Satyanarayana, 2009). However, of these, only Pillai and Patel (1988), Patel (1978) and Deshmukhe *et al.* (2000) have given location specific species / generic richness of the coral taxa. Till date total 59 species belonging to 27 genera of scleractinian corals have been recorded under various studies. Out of 59 species recorded in GoK 5 are listed as VULNURABLE, 16 as NEAR THREATENED

and 8 DATA DEFICIENT (IUCN 2010). All of these studies were confined only to the inter-tidal zone of the Gulf of Kachchh.

Most of the healthy coral growth in the GoK is confined to the lower strata *i.e.* reef edge and reef slope. Such area gets exposed for a very limited period only during negative tides, when water recedes to a greater extent. However, it might be possible that the studies carried out till date were confined to the upper strata of reefs which gets exposed daily and the rich lower strata was overlooked.

The 38 species belonging to 20 genera recorded during the present study, have already been reported earlier from the Gulf of Kachchh. Though *Turbinaria peltata* and *Turbinaria reniformes,* the VULNURABLE (IUCN 2010) species, were recorded from Poshitra and Asaba Pir, the present study shows *T. peltata* to be the most frequently occurring species at Poshitra with relative frequency of 29%. However, it was also recorded from Narara and Kalubhar but with negligible frequency. Of the eight species categorized as NEAR THREATENED species (IUCN 2010) *viz. Acanthastrea hillae, Favites complanata, Goniopora minor, Pseudosiderastrea tayami, Montipora foliosa,Favites bastae, Montipora venosa* and *Platygyra lamaelinna,* in the present study first four were found to be well distributed on GoK reefs, while the fifth species *M. foliosa* though not widely distributed was the most common species at Asaba Pir. The moderate distribution of remaining two species (at 3 to 4 locations) but with low frequency of occurrence indicate that the species considered as near threatened are either thriving well or trying to sustain themselves in GoK.

There were six species *viz. Platygyra daedella, Goniopora sp., Plesiastrea versipora, Symphillia radians, Turbinaria reniformes, Tubastrea aurea* confined to Asaba Pir and Poshitra only where the turbidity was comparatively low, Dissolved Oxygen and pH high (Chapter 7), submergence during the low tide was for longer period and

movements of large vessels were almost nill due to its location in Poshitra bay. These two reefs are probably the most undisturbed reefs, where more species could survive. These species did not occur in any other location and were confined to the western parts of the gulf. Where the conditions are still under limits and anthropogenic threats minimum. At this point trends can still be reversible and conditions can be improved.

Pillai and Patel (1988) recorded total 37 species from sixteen locations of Gulf of Kachchh, of which 5 species were not recorded in the present study from any of the location. Amongst four common sites studied between Pillai and Patel (1988) and present studies (Pirotan, Goose, Narara, Kalubhar), at least 13 species could not be recorded at Pirotan, 6 species could not be recorded from Goose, 1 species from Narara and 3 species from Kalubhar. These all are the locations in most disturbed area of gulf. Hence, disappereance of some species may be correlated to the industrial development which is known to be one of the major threat to the biodiversity of this area. Reid (1992) have reported that biodiversity loss is increasingly impairing the accelerating loss of population and species.

Satyanarayana (2009) has listed total 49 species of hard corals from GoK, which include 37 species described by Pillai and Patel (1988) and 12 more species which were not reported earlier from this area. However, Satyanarayana (2009) has not referred the works carried out by Patel (1978; 1985) and Pillai and Patel (1988) in his book, which are considered to be the pioneering studies for the taxonomy of corals in the GoK. Unfortunately Satyanarayana (2009) has neither clarified the status of the 37 species listed by Pillai and Patel (1988), nor has mentioned site lo cality of any of the species listed, including 12 new records for the area. Out of these 12 new records, 4 are the first record for the country by Satyanarayana (2009). Because of these sporadic records one cannot infer distribution or actual existance or status of any of the species of corals in the GoK.

Out of 12 new records for GoK (Satyanarayana, 2009), at least two species were recorded in the present study *viz*. *Barabattoia amicorum* and *Turbinaria frondes* at Asaba Pir.

Patel (1978) described the generic diversity of corals around Poshitra, of which four genera *viz. Leptoria*, *Pavona*, *Podabacia* and *Pachyseris* are not reported in any of the consequent publications pertaining to corals, including his own (Patel, 1985; Pillai and Patel, 1988). The work carried out on Sikka and Vadinar coastal coral reefs (Kundu, 2001) recorded 16 species of corals. Out of these, *Meandrina arabica* and *Flavellum flavum* have not been reported in any of the publications on corals of GoK, and were not recorded during the present study also. Kundu (2001) has also mentioned that the *Meandrina arabica* was dominant on the coast during his study; however the existence of genus is confirmed but there is no evidence of the species (Veron 2000). Unfortunately he has not claimed first record of the species from the country also. Veron (2000) has shown occurrence of this genus from Brazil and there exist no earlier record from India. The existence of this species needs species specific investigations. Dave (20011) has given comprehensive account of Narara reef, recording 27 species of hard corals from Narara reef only.

Sedimentation is reported to be a major factor influencing corals and coral communities (Rogers, 1990; Rigel *et al.* 1995; Done, 2010). The naturally high rates of sedimentation on the fringing reefs may cause considerable coral mortality. Many corals experience high sedimentation stress throughout the year due to continuous dredging by the port / jetty authorities to maintain ship traffic. At GoK this is observed especially in the eastern and central part (near the study locations Pirotan, Goose, Narara and Kalubhar). Consequently, it is difficult to specify the threshold values of sedimentation, above which anthropogenic causes can be mitigated. Some reviews on the effects of sedimentation on coral reefs suggest severe to catastrophic effects resulting from sedimentation rates of >50

mg/cm^2/d (Rogers 1990). The coral genera belonging to Favidae and Poritidae are able to withstand strong wave action due to their massive or submassive growth forms and can tolerate high levels of sedimentation (Ayling and Ayling, 1991; Berkelmans and Oliver, 1999), while the coral groups that are more susceptible to bleaching and wave impacts are *Acropora* and *Pocillopora* corals (Wilkinson, 2008), which are not recorded from these reefs during the present study. The past records of these species are only of dead specimen (skeletal) (Pillai and Rajagopalan, 1979; Pillai and Patel, 1988; Styanarayana, 2009). The reason could be due to the high silting (Pillai and Rajagopalan, 1979) considers this to be because of high siltation.

Dead fragments of *Acropora* genus were recorded through out the GoK, including six study locations. Maximum density of such fragments was observed regularly at Boria during the field trips. The dead fragments of *Acropora* suggest the possibility of subtidal reef and good generic diversity in the subtidal regions of GoK. In the other major coral reefs of India *viz*. Lakshadweep, Gulf of Mannar and Andaman Nicobar, most of the surveys have taken place in the subtidal regions only where the possibility of the coral abundance and richness is always higher. The survival of these branching corals, especially *Acropora* genus, contributes a large amount to the species richness of the scleractinian corals of these reefs (Pillai, 2010; Balasubramaniam and Kahn, 2001). However from the reefs of GoK, till date only 3 species of dead *Acropora* have been reported. This fact lead to two hypothesis

(1) *Acropora* has become extinct in GoK

(2) Area having live Acropora in GoK is yet not identified, since *Acropora* is known to occur in subtidal area (Veron, 2000), it could be the main reason why its live specimens are not yet found in GoK.

Species of *Favia* genus *i.e. F. speciosa* and *F. favus* with maximum relative frequency at Pirotan, Goose and Narara of 41, 51 and 37.8 respectively, shows monospecific assemblages indicating greater "*limits of tolerance"* (Schefield's Law of tolerance) of the species (Fig: 5.24). These species which can adapt to a broad spectrum of habitats along with greater limits of tolerance are known as "Generalist species" (Krebs and Davies, 1993). The frequency of remaining species of corals were very low, indicating their low tolerance limits towards the environmental fluctuations. Such species are called Specialised species (Krebs and Davies, 1993). The number of such species is always high in the given habitat (Michael, 1986). The habitats or even ecosystems dominated by single genus / species is not a good sign of healthy ecosystem (Bawa *et al.* 2011).

Tolerance of these generalist coral species of GoK can be attributed to the growth forms and the size of their corallite. *F. speciosa* and *F. favus* have massive to encrusting growth forms whereas *Porites lutea* showed maximum frequency at Kalubhar during the current study. This species has encrusting and submassive type of growth (Veron, 2000). The massive, submassive and encrusting types of growth forms are such in shape that they do not allow sediments to settle on the colony (Prasanna, 2008). Whereas, the folacious growth forms of *Montipora venosa* are not able to avoid the settling of sediments due to their plate like growth forms. Hence, the good presence of such coral species with folacious or platelike growth indicates more stable environment in terms of sedimentation and local disturbances. *Turbinaria peltata* frequently observed in Poshitra has tabular / plate like or some times funnel shaped growth forms and can also adapt to average sedimentation with changing environment (Riegl *et al.* 1995). The general values of Total Suspended Matter (TSM) in the Northern and North eastern part of GoK ranges between 21 to 89 mg / l, where Kandla and Mundra ports are operational with very high vessel traffic. However the range of TSM in southern parts having coral reefs, ranges from 15 to

40 mg/l (Chauhan *et al.* 2006) which is low compared to the northern gulf but is very high when compared to the other coral reefs of India as well as World.

However, there is no specific study which indicates, reef specific sedimentation rates of this area, but some reports (Chauhan *et al.* 2006; Kunte *et al.* 2005) have described the Total Suspended Matter (TSM) flow through the remote sensing techniques. According to Chauhan *et al.* (2006), the GoK waters can be classified as turbid. For the survival of a fragile ecosystem of corals with the maintenance of the navigational channels of existing and upcoming harbours / jetties, the determination of specific sources of turbidity, its dispersal pathways and influence on morphodynamic processes are very crucial (Pradhan *et al.* 2004). It is very important to understand and monitor the dredging processes and its disposal taking place in the gulf regardless to the distance as it adds to the total turbidity of the gulf water.

The major source of sedimentation in GoK can be considered the Indus discharge, which is situated about 100 km, north of the gulf, discharging about 435 million tons of sediments annually, through the delta of 8500 km^2 (Desa *et al.* 2005). However Nair *et al.* (1982) have reported 200 million tons sediment discharge annually, which, due to the high tidal circulations, keep on circulating in the gulf causing resuspension (Kunte *et al.* 2004).

Percent cover of live coral is by far the most widely used matrix of coral reef condition and is universally used in studies that document coral reef decline and recovery across large spatial scales (Bellwood and Huges, 2001; Pandolfi *et al.* 2003; Bruno and Selig, 2007). Determining regional trends in coral cover is difficult due to the large spatial and temporal scales involved. The variability and dynamic nature of disturbance events that shape reef communities indicate that small scale studies can easily miss or over represent the impact of localised disturbance events (Osborne, 2011).

The average live coral cover of the six locations in the gulf is 22%, which can be considered low, compared to the other reef areas of India *i.e.* Lakshadweep (32% - Arthur, 2000) (50 to 60% - Anita Mary George, 2008), and Gulf of Mannar (33.6% - Arthur, 2000). Hoon (1997), also indicated the average live coral cover of GoK, to range between 20 to 30%. A noticable trend in live coral cover, frequency and species richness of corals (Fig: 5.25) is observed in the present study. While moving from east to west in the gulf these three parameters of corals showed increasing trend. Pirotan, Goose, Narara and Kalubhar are having significantly low coral coverage and poor richness compared to Poshitra and Asaba Pir, situated on the western extremes of the gulf. Such trend / difference in the two zones can be due to the following reason,

(1) Exploitation of reefs for cement industry: Before the area was declared as PA, reefs like Jindra, Pirotan, Goose, Narara and Kalubhar were given on lease to exploit the sand and other calcium material from the reef (Patel, 1978). It is reported that 1675 tonnes calcium sand was required for the production of 1531 tonnes of cement per day. Such setup was functional since 1946-47 (Patel, 1985). As the coral skeleton are rich in calcium, it might be possible that live corals also would have been exploited for the calcium requirement of the industry along with the sand. This had also destroyed considerable amount of mangroves from Jindra island (Patel, 1985). Narara was one of the good nesting site for sea turtles, which was demolished completely due to the heavy exploitation (Patel, 1985). Massive *Porites* one of the most important reef builder, have been removed from Pirotan for various purposes, and very few colonies are surviving (Pillai and Rajagopalan, 1979). In the present study, % of live coral cover recorded at Pirotan was 14.3% with relative frequency of *Porites lutea* to be 26.7% and *Porites solida* to be 12.2%.

(2) Industrialisation: The current industrialisation taking place in the southern part of gulf is mainly confined to the central and eastern parts of GoK. Two large oil refineries have been established in the central and eastern part *i.e.* at Sikka and Vadinar (Zingde and Anand, 1994), coal based power plant of GSECL is also operational at Sikka, a fertiliser unit and many more small scale industries are growing on the east-central coast of the southern GoK. Majority of these industries heavily depend on the marine water for one or the other purpose. Further, to maintain the oil vessel traffic for the refineries, continuous dredging is being carried out. Such activities contribute to pollution and Turbidity to the marine waters.

(3) Human activity: The upper strata includes reef flat that gets exposed during each ebb tide twice in a day. The resources available on the this strata can be easily accessible than that of the lower strata, hence there is significant human movement and degradation in the upper strata than the lower strata. As it gets exposed regularly, it is misidentified as low coral abundance area.

While performing ANOVA, followed by Bonferroni Multiple Comparison Test, the results revealed significant difference between Pirotan with Goose, Narara, Poshitra Asaba Pir, significant difference between Goose and Narara, Kalubhar, and Poshitra, Kalubhar and Poshitra and Asaba Pir. However between Pirotan and Kalubhar, Goose and Asaba Pir, and Poshitra and Asaba Pir, there was no significant difference in the live coral cover. This can be due to the geo morphology of the area, as Pirotan and Kalubhar both are islands fringed with coral reefs, while Goose and Asaba Pir are the two submerged reefs which gets exposed for a limited period of time during low tides. So it can be said that the geomorphology of the reef is also playing important role in determining the live coral status of that reef.

In the past also the reefs in the eastern and central GoK were exploited and has suffered heavy degradation. Instead of improving the efforts for conservation, maximum modern industrialisation is taking place in the same region, leading the eastern and the central gulf towards heavy ecological degradation, with reference to the coral reefs. If the condition persist for the longer duration, it is possible that major coral growth will be confined to some parts of the western GoK only.

A major bleaching of corals was recorded worldwide in July 2010 (Krishnan *et al.* 2011), which was confirmed at Poshitra in October 2010 when visited with the team of GEER Foundation – Gandhinagar (unpublished record). At Poshitra though 90% bleaching was noted, subsequently in March 2011 visit *i.e.* within six months, complete recovery was observed (Table 5.21). There was no mortality due to the bleaching of any coral colony was recorded. Such phenomenon has been earlier studied and reported (Arthur, 2000), which also could not record any mortality of corals due to coral bleaching in the year 1998 due to El Nino southern oscillations, stating that the coral colonies surviving in GoK are tolerant towards the environmental fluctuations.

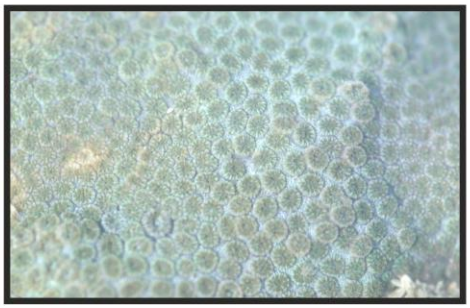
The average live coral cover in the GoK ranges from 3.51% at Narara to 41.6% at Poshitra. In the present study the central gulf locations *i.e.* Narara has shown maximum degradation of live corals in both upper and lower strata, followed by Goose and Pirotan in the eastern gulf and Kalubhar in the central gulf. The locations of the western gulf are having relatively good coral conditions.

The history of these reefs reveals that even before the area was declared as MPA, the dredging of sand and other calcium resources were more on the eastern and central parts of the southern GoK. Whereas the western parts were relatively less disturbed. In the current study also, maximum industrial pressure is noted on the central and eastern parts of the gulf. Considering the coral growth physiology, if such pressure continues for a longer

duration, the corals will become restricted to the some patches of western gulf. The results of the current study clearely indicates heavy degradation in the central and eastern parts of the GoK with reference to live coral cover and coral species richness, which points out towards the past exploitation of the reefs of eastern and central gulf area and current industrialization, which is also buiding rapid pace in the eastern and central GoK.

Plate 5.1: Hard corals recorded at six study locations

Acanthastrea hillae



Cyphastrea seralia

Coscinarea monile

Goniopora minor

Goniopora nigra

Goniastrea pectinata

Favia speciosa

Favia favus

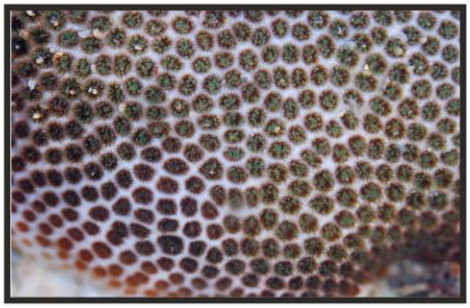
Plate 5.2: Hard corals recorded at six study locations

Favites complanata

Favites sp. 1

Montipora foliosa

Montiopora venosa



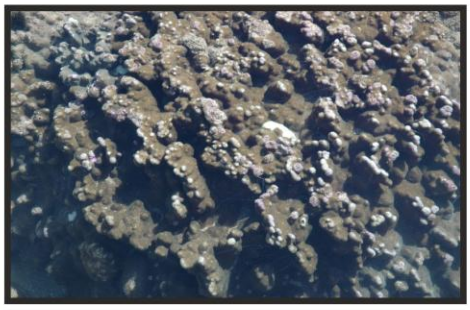
Pseudosiderestrea tayami

Siderestrea savigyna

Platygyra lamelina

Platygyra sinensis

Plate 5.3: Hard corals recorded at six study locations



Porites lutea

Porites compressa

Symphillia recta

Symphillia radians

Turbinaria peltata

Turbinaria reniformis

Parycyathus stokessi

Tubastrea aurea

Plate 5.4: Hard corals recorded at six study locations

Barabattoia amicorum

Turbinaria frondes

6. ASSOCIATED FAUNA

CHAPTER 6
ASSOCIATED FAUNA

6.1 INTRODUCTION

Reef animals other than corals are overwhelmingly the most conspicuous components of coral reef life, truly occurring in density and diversity in almost every part of reef ecosystem. Most of the invertebrate phyla of animal kingdom are represented on the coral reefs. They are the primary builders of coral reefs and an integral part of many aspects of the ecology of coral reef ecosystems.

Invertebrates occur in all coral reef zones and habitats and, are instrumental in the movement and cycling of nutrients through the ecosystem (Venkatraman, 2003). Many of them live in reef sediments, and engage in activities such as burrowing or tunnelling that shape the very nature of these ecosystems. Some of the most important groups of these coral reef associates are Poriferas (sponges), Cnidarians (Other than corals), Molluscans, Crustaceans, Echinoderms, Helminthes and other worms. Some of these can act as indicators of the coral reef status, by showing their abundance on the reef. The abundance of these invertebrates can be for shelter, food or any other purpose.

Being the second largest animal phylum after Arthropoda, Mollusca is one of the major contributor to the reef diversity. Marine molluscan diversity of the Indian coast is well studied. In India 5070 species of mollusca have been recorded of which 3500 + are from the marine habitats (ZSI, 2004). Andaman and Nicobar regions have a rich diversity of these Molluscs, which include more than 1000 species (Venkatraman, 2003). Taxonomic studies on marine molluscs in Gujarat include two major studies (Hornel, 1909; Kundu, 1965). However, no association of this group has been established with the coral reefs of GoK. Hence, in the current study emphasis is given to this group of animals,

especially opisthobranchs. However a separate list of other invertebrate associates of the study locations is given separately at the end of the chapter with plates.

Opisthobranch gastropods vary in size from the tiny herbivorous sacoglossans to the sand-dwelling acochlidiaceans, to the huge *Tochuina tetraquetra* of the Pacific N.W. of America, and the *Aplysia* and *Dolahella* species of tropical waters, weighing in air as much as 2 kg. Some may be found only by diving, digging or searching beneath boulders or coral heads; others, like some of the tropical chromodorid nudibranchs, often appear bold and self-advertising (Thompson, 2003). The Opisthobranch fauna of Gulf of Kachchh has been described by Narayan (1969) and recently by Apte *et al.* (2010). However, the quantification, status and association with coral reef have not been recorded for the reefs of GoK.

Quantified data was collected through belt transects of 20 meters with 1 meter width, at every 50^{th} quadrate of the coral objectives. Total 37 transects were taken from six study locations. Specimens were photographed and identified using standard field guides (Gosliner *et al.* 2008).

6.2 RESULTS

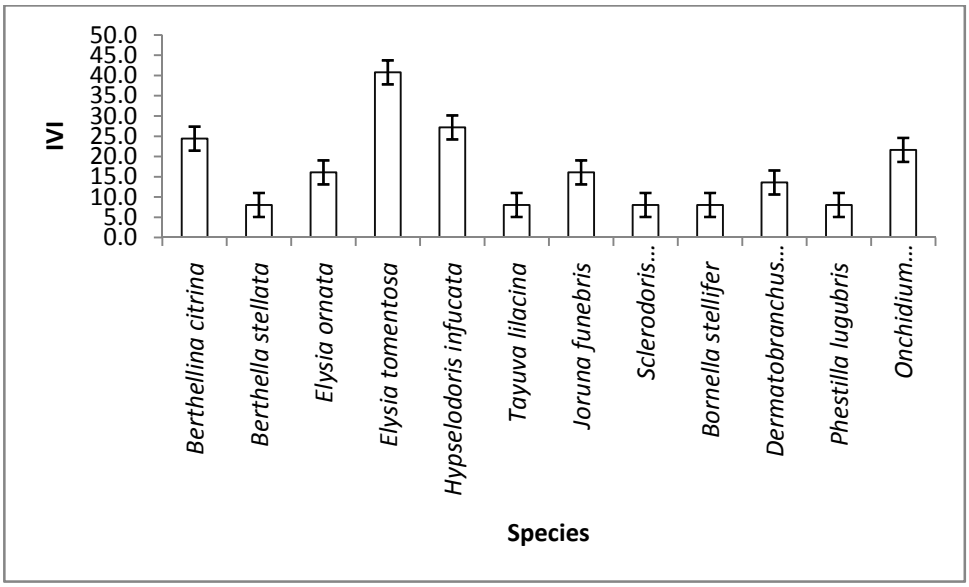
Pirotan Island (Table 6.1, Fig 6.1)

Total 36 individuals belonging to 12 species were recorded from the reef of this island. *Elysia tomentosa* was the most dominant species (IVI = 40.8), followed by *Hypselodoris infucata* (IVI = 27.2) and *Bertellina citrina* (IVI = 24.4), while single specimen of *Phestilla lugubris*, *Sclerodoris tuberculata*, *Berthella stellata* and *Bornella stellifer* were recorded. Maximum diversity (3 species) was recorded under family Doridiidae followed by Pleurobranchidae (2 species) and Elysidae (2 species). The Shannon-Weineer index for the opisthobranchs was 2.1 and the evenness was 0.86. *Elysia tomentosa* was most frequently occurring species (Relative frequency 15.8%). The average density of opisthobranch at Pirotan was 36 / 100 m^2.

Table: 6.1 Important Value Index (IVI) of the Opisthobranch species at Pirotan

Sr. No.	Species	IVI
1	*Berthellina citrina*	24.4
2	*Berthella stellata*	8.0
3	*Elysia ornate*	16.1
4	*Elysia tomentosa*	40.8
5	*Hypselodoris infucata*	27.2
6	*Tavuya lilacina*	8.0
7	*Joruna funebris*	16.1
8	*Sclerodoris tuberculata*	8.0
9	*Bornella stellifer*	8.0
10	*Dermatobranchus fortunata*	13.6
11	*Phestilla lugubris*	8.0
12	*Onchidium verruculatum*	21.6

Fig: 6.1 Important Value Index (IVI) of the Opisthobranch species at Pirotan



Goose Reef

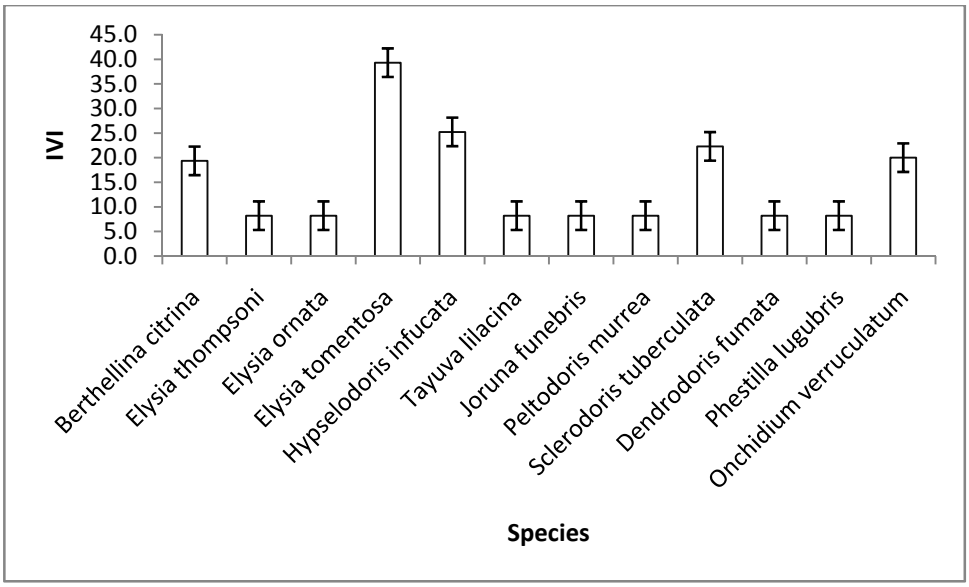
Total 34 specimens belonging to 12 species of 7 families were recorded on Goose reef. *Elysia tomentosa* was the most dominant species (IVI = 39.3), followed by *Hypselodoris infucata* (IVI = 25.2) and *Scerodoris tuberculata* (IVI = 22.3) (Table 6.2: Fig 6.2). Single specimen was recorded for seven species *viz. Elysia thompsoni, Elysia ornata, Tayuva lilacina, Joruna funebris, Petodoris murrea, Dendrodoris fumata and Phestilla lugubris.* Maximum diversity was recorded in family Doridiidae (4 species) followed by Elysidae (3 species). The average density of opisthobranchs at Goose was 34 / 100 m^2. The Shannon-Weiner Index for the opisthobranchs was 2.1 and the evenness was 0.86.

Table 6.2: Important Value Index (IVI) of the Opisthobranch species at Goose

Sr. No.	Species	IVI
1	*Berthellina citrina*	19.3
2	*Elysia thompsoni*	8.2
3	*Elysia ornata*	8.2
4	*Elysia tomentosa*	39.3
5	*Hypselodoris infucata*	25.2
6	*Tayuva lilacina*	8.2

7	*Joruna funebris*	8.2
8	*Peltodoris murrea*	8.2
9	*Sclerodoris tuberculata*	22.3
10	*Dendrodoris fumata*	8.2
11	*Phestilla lugubris*	8.2
12	*Onchidium verruculatum*	20.0

Fig 6.2: Important Value Index (IVI) of the Opisthobranch species at Goose



Narara Coast (Table 6.3, Fig 6.3)

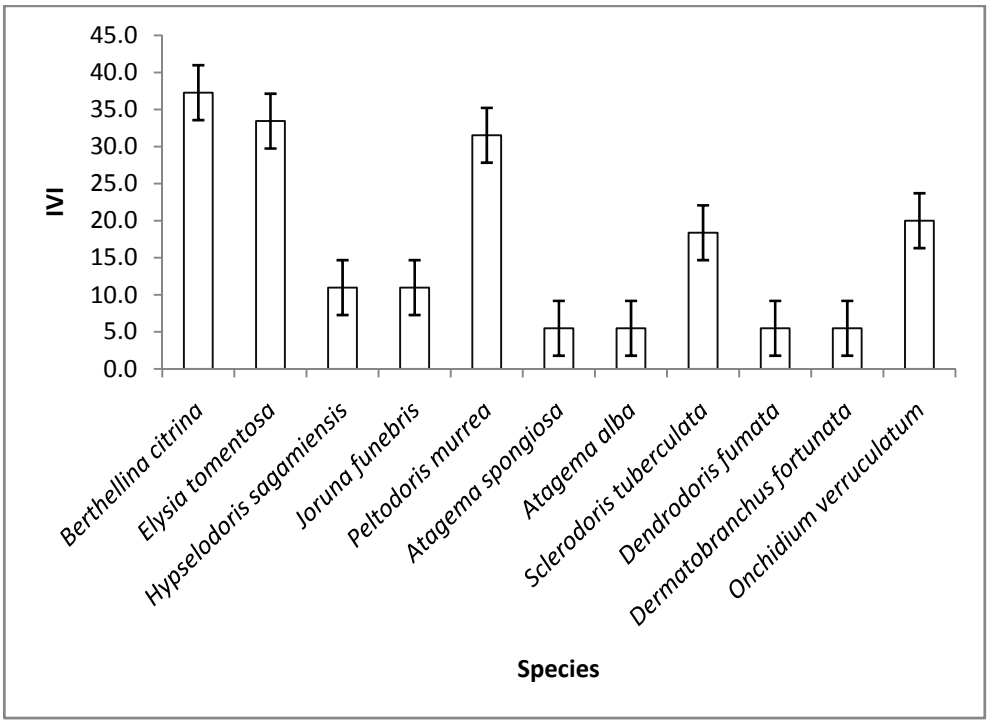
Total 52 individuals belonging to 11 species were recorded from the reef of this coast. *Berthelinna citrina* was the most dominant species (IVI = 37.3), followed by *Elysia tomentosa* (IVI = 33.4) and *Peltodoris murrea* (IVI = 31.5) while, single specimen of *Ategama spongiosa, Ategama alba, Dendrodoris fumata* and *Dermatobranchus fortunata* were recorded. Maximum diversity (5 species) was recorded from family Doridiidae while remaining five families contributed only one species each. The average density of the opisthobranch fauna at Narara was 29 / 100 m^2. Most frequently occurring species were *Peltodoris murrea, Elysia tomentosa* and *Berthellina citrina* (Relative Frequency = 14.3%

each). The Shannon-Weiner index for the opisthobranchs was 2.01 and the evenness was 0.84.

Table: 6. 3 Important Value Index (IVI) of the Opisthobranch species at Narara

Sr. No.	**Species**	IVI
1	*Berthellina citrina*	37.3
2	*Elysia tomentosa*	33.4
3	*Hypselodoris sagamiensis*	11.0
4	*Joruna funebris*	11.0
5	*Peltodoris murrea*	31.5
6	*Atagema spongiosa*	5.5
7	*Atagema alba*	5.5
8	*Sclerodoris tuberculata*	18.4
9	*Dendrodoris fumata*	5.5
10	*Dermatobranchus fortunata*	5.5
11	*Onchidium verruculatum*	20.0

Fig: 6. 3 Important Value Index (IVI) of the Opisthobranch species at Narara



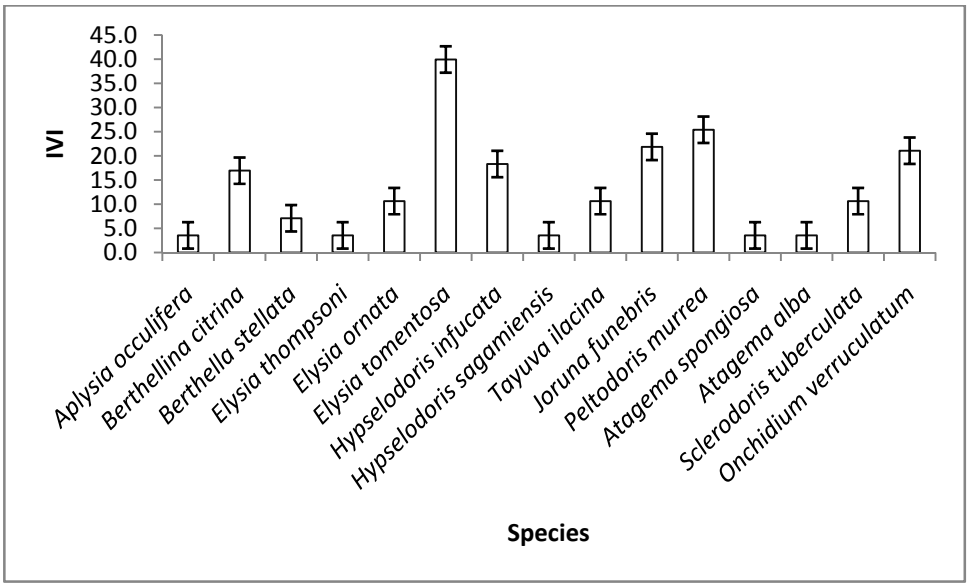
Kalubhar Island (Table 6.4, Fig 6.4)

At Kalubhar total 73 specimens belonging to 15 species of six families were recorded. *Elysia tomentosa* was the most dominant species (IVI = 40), followed by *Peltodoris murrea* (IVI = 25.4) and *Joruna funebris* (IVI = 24). Single specimen was recorded for five species *viz. Aplysia oculifera, Elysia thompsoni, Hypselodoris sagamiensis, Atagema spongiosa and Atagema alba,* Maximum diversity was recorded for Doridiidae family (6 species) followed by Elysidae (3 species). The average density of opisthobranchs at Kalubhar was 28 / 100 m^2 with Shannon-Weiner Index 2.3 and 0.86 evenness.

Table 6.4 Important Value Index (IVI) of the Opisthobranch species at Kalubhar

Sr. No.	Species	IVI
1	*Aplysia occulifera*	3.5
2	*Berthellina citrina*	16.9
3	*Berthella stellata*	7.1
4	*Elysia thompsoni*	3.5
5	*Elysia ornata*	10.6
6	*Elysia tomentosa*	39.9
7	*Hypselodoris infucata*	18.3
8	*Hypselodoris sagamiensis*	3.5
9	*Tayuva lilacina*	10.6
10	*Joruna funebris*	21.9
11	*Peltodoris murrea*	25.4
12	*Atagema spongiosa*	3.5
13	*Atagema alba*	3.5
14	*Sclerodoris tuberculata*	10.6
15	*Onchidium verruculatum*	21.1

Fig: 6.4 Important Value Index (IVI) of the Opisthobranch species at Kalubhar



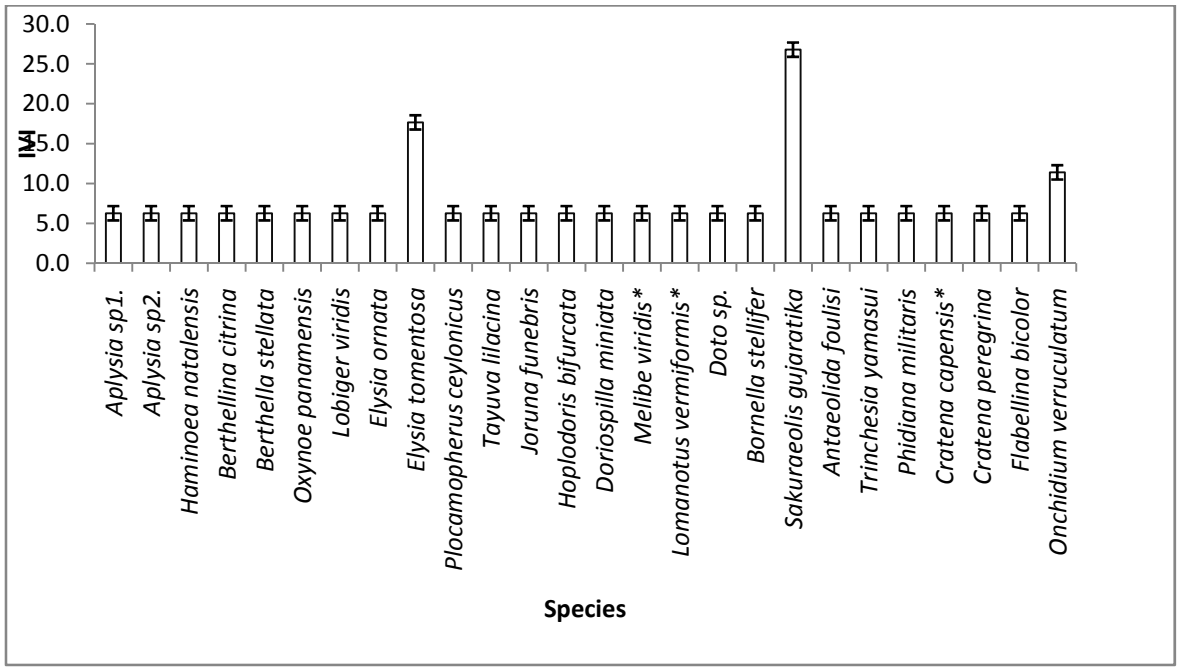
Poshitra Coast (Table 6.5, Fig 6.5)

Total 39 specimens belonging to 26 species of seventeen families were recorded at Poshitra. *Sakuraeolis gujaratika* was the most dominant species (IVI = 26.8) and is also a type locality / endemic species (Rudman, 1980), followed by *Elysia tomentosa* (IVI = 17.7). Except *Sakuraeolis gujaratika, Onchidium verruculum* and *Elysia tomentosa* all the other species had only single occurrence. Maximum diversity was recorded for two families *viz.* Doridiidae and Glaucidae with 3 species each, followed by Eolidae, Elysidae, Oxynoidae and Pleurobranchidae with two species each. The average density of opisthobranchs at Poshitra was 97 / 100 m^2. The Shannon-Weiner Index for the opisthobranchs was 2.93 and the evenness 0.9.

Table: 6.5: Important Value Index (IVI) of the Opisthobranch species at Poshitra

Sr. No.	Species	IVI
1	*Aplysia sp1.*	6.3
2	*Aplysia sp2.*	6.3
3	*Haminoea natalensis*	6.3
4	*Berthellina citrina*	6.3
5	*Berthella stellata*	6.3
6	*Oxynoe panamensis*	6.3
7	*Lobiger viridis*	6.3
8	*Elysia ornata*	6.3
9	*Elysia tomentosa*	17.7
10	*Plocamopherus ceylonicus*	6.3
11	*Tayuva lilacina*	6.3
12	*Joruna funebris*	6.3
13	*Hoplodoris bifurcata*	6.3
14	*Doriospilla miniata*	6.3
15	*Melibe viridis*	6.3
16	*Lomanotus vermiformis*	6.3
17	*Doto sp.*	6.3
18	*Bornella stellifer*	6.3
19	*Sakuraeolis gujaratika*	26.8
20	*Antaeolida foulisi*	6.3
21	*Trinchesia yamasui*	6.3
22	*Phidiana militaris*	6.3
23	*Cratena capensis*	6.3
24	*Cratena peregrina*	6.3
25	*Flabellina bicolor*	6.3
26	*Onchidium verruculatum*	11.4

Fig: 6.5: Important Value Index (IVI) of the Opisthobranch species at Poshitra



Asaba Pir Reef (Table 6.6 Fig 6.6)

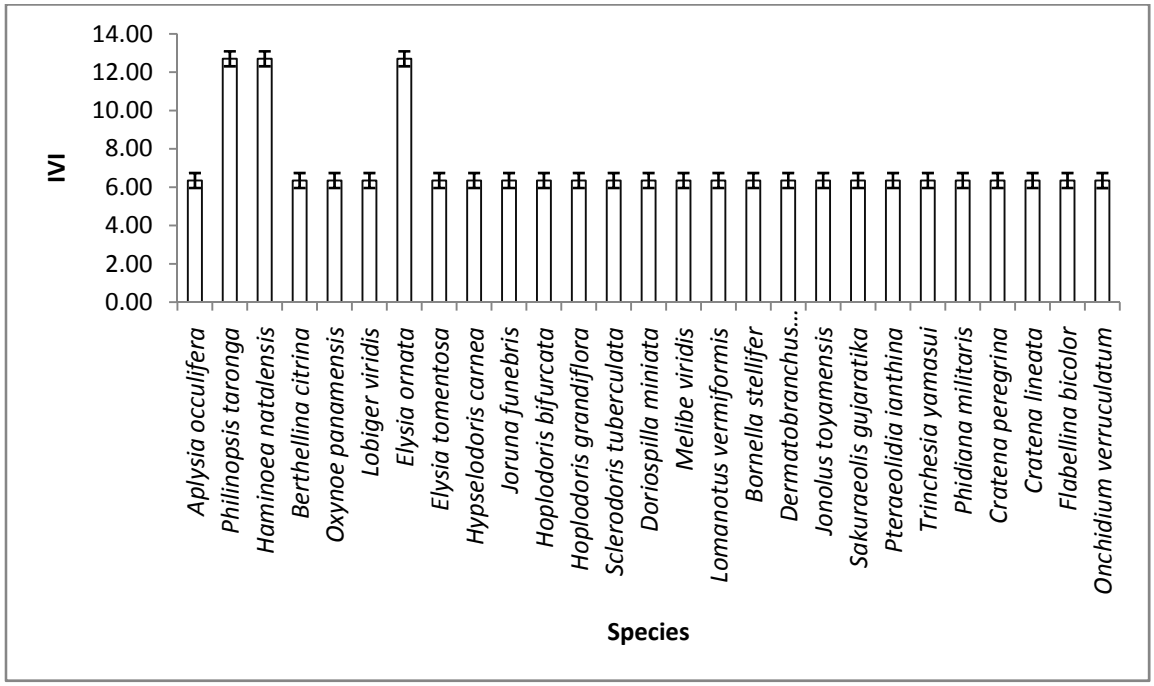
Total 32 specimens belonging to 27 species of to 19 families were recorded at Asaba Pir. *Philinopsis taronga, Haminoea natalensis and Elysia ornata* were the most dominant species (IVI = 12.7, each) with, rest of all species recorded by single specimen. Maximum diversity was recorded in doriididae family (4 species) followed by glaucidae (3 species). The average density of opisthobranchs at Asaba Pir was 40 / 100 m^2 while Shannon-Weiner Index was 3.2 and the evenness 0.9.

Table: 6.6: Important Value Index (IVI) of the Opisthobranch species at Asaba Pir

Sr. No.	Species	IVI
1	*Aplysia occulifera*	6.35
2	*Philinopsis taronga*	12.70
3	*Haminoea natalensis*	12.70
4	*Berthellina citrina*	6.35
5	*Oxynoe panamensis*	6.35
6	*Lobiger viridis*	6.35
7	*Elysia ornata*	12.70
8	*Elysia tomentosa*	6.35

9	*Hypselodoris carnea*	6.35
10	*Joruna funebris*	6.35
11	*Hoplodoris bifurcata*	6.35
12	*Hoplodoris grandiflora*	6.35
13	*Sclerodoris tuberculata*	6.35
14	*Doriospilla miniata*	6.35
15	*Melibe viridis*	6.35
16	*Lomanotus vermiformis*	6.35
17	*Bornella stellifer*	6.35
18	*Dermatobranchus fortunata*	6.35
19	*Jonolus toyamensis*	6.35
20	*Sakuraeolis gujaratika*	6.35
21	*Pteraeolidia ianthina*	6.35
22	*Trinchesia yamasui*	6.35
23	*Phidiana militaris*	6.35
24	*Cratena peregrina*	6.35
25	*Cratena lineata*	6.35
26	*Flabellina bicolor*	6.35
27	*Onchidium verruculatum*	6.35

Fig: 6.6: Important Value Index (IVI) of the Opisthobranch species at Asaba Pir



6.3 Comparative Analysis of six sites

Species Richness (Fig: 6.7 & 6.8, Table 6.7)

Total 43 species of Opisthobranchs belonging to 21 families were recorded over the study. Maximum richness of 27 species belonging to 19 families was recorded at Asaba Pir, followed by Poshitra with 26 species belonging to 17 families. Minimum species richness was recorded at Narara with only 11 species belonging to 7 families. Doridiidae was the most diverse family contributing 8 species, followed by Glaucidae, which contributed 4 species, whereas, 13 families were represented by only one species each.

Fig: 6.7: No of families and species richness of Opisthobranchs represented at six study locations

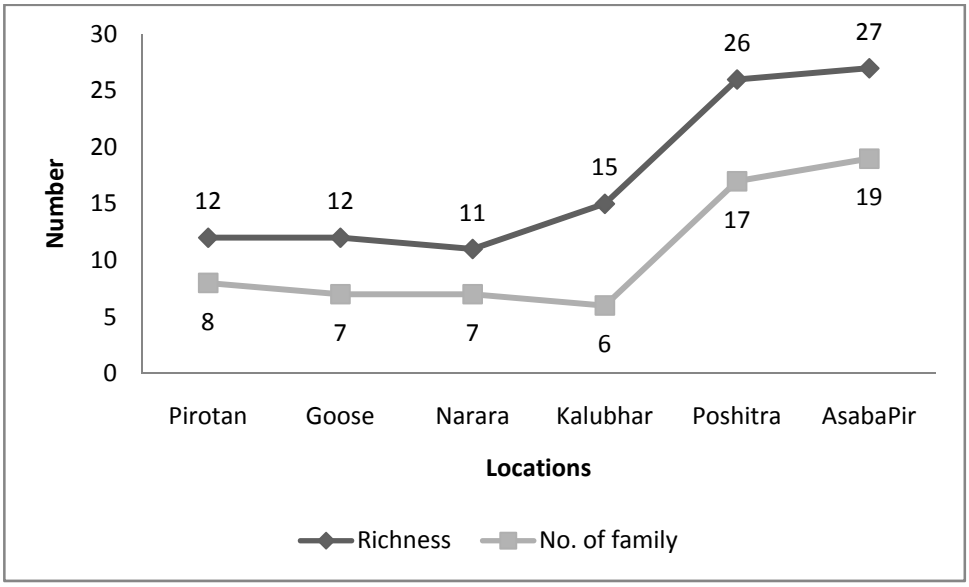


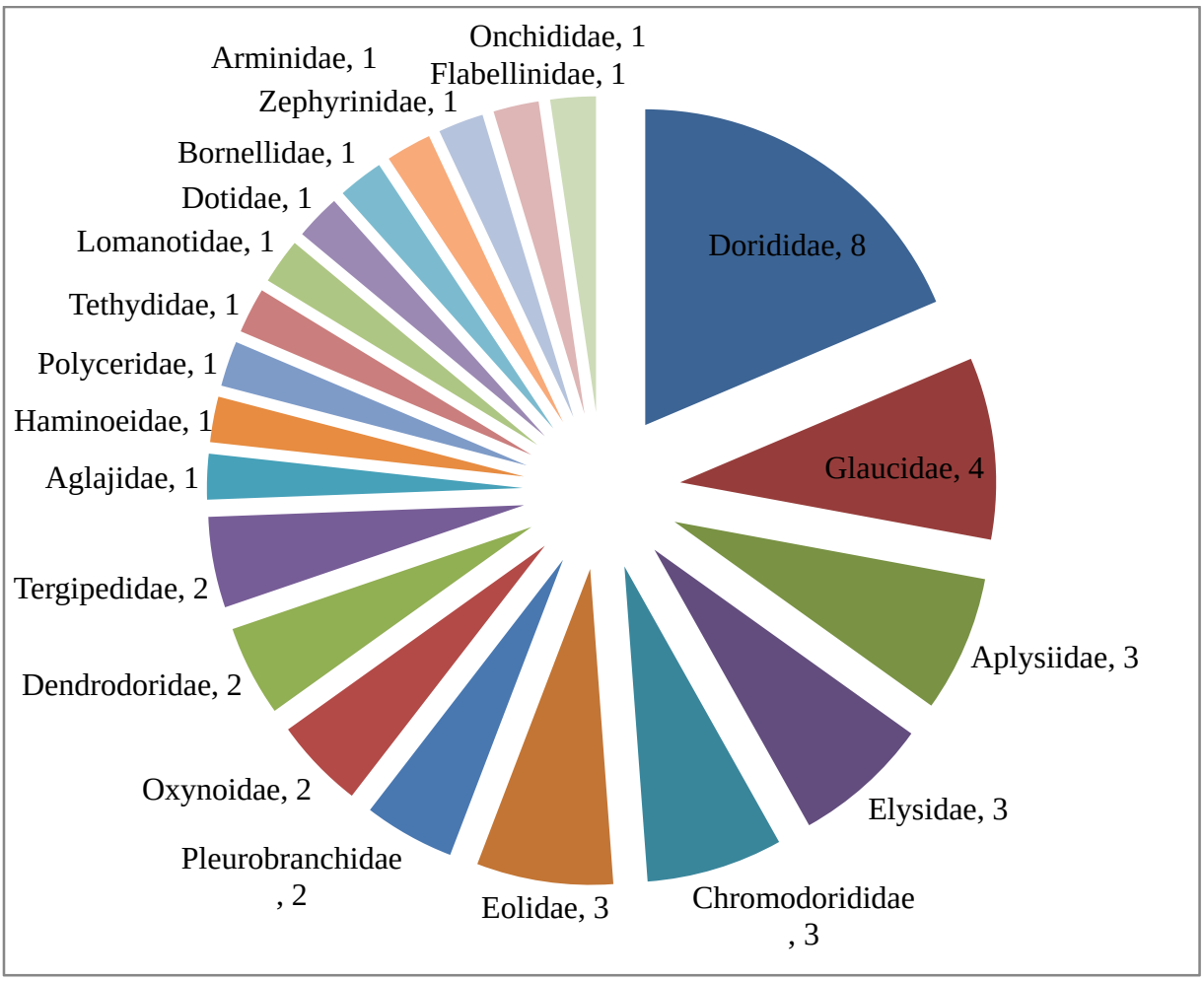
Table: 6.7: List of Opisthobranch species recorded at six study locations (Plate 6.1, 6.2, 6.3, 6.4)

Sr. No.	Family	Species	Pi	G	N	K	Po	A
1	Aplysiidae	*Aplysia occulifera*	-	-	-	*	-	*
2		*Aplysia sp1.*	-	-	-	-	*	-
3		*Aplysia sp2.*	-	-	-	-	*	-
4	Aglajidae	*Philinopsis taronga*	-	-	-	-	-	*
5	Haminoeidae	*Haminoea natalensis*	-	-	-	-	*	*
6	Pleurobranchidae	*Berthellina citrina*	*	*	*	*	*	*
7		*Berthella stellata*	*	-	-	*	*	-
8	*Oxynoidae*	*Oxynoe panamensis*	-	-	-	-	*	*
9		*Lobiger viridis*	-	-	-	-	*	*
10	Elysidae	*Elysia thompsoni*	-	*	-	*	-	-
11		*Elysia ornate*	*	*	-	*	*	*
12		*Elysia tomentosa*	*	*	*	*	*	*
13	Polyceridae	*Plocamopherus ceylonicus*	-	-	-	-	*	-
14	Chromodorididae	*Hypselodoris infucata*	*	*	-	*	-	-
15		*Hypselodoris carnea*	-	-	-	-	-	*
16		*Hypselodoris sagamiensis*	-	-	*	*	-	-
17	Doridiidae	*Tayuva lilacina*	*	*	-	*	*	-
18		*Joruna funebris*	*	*	*	*	*	*
19		*Peltodoris murrea*	-	*	*	*	-	-
20		*Atagema spongiosa*	-	-	*	*	-	-
21		*Atagema alba*	-	-	*	*	-	-
22		*Hoplodoris bifurcata*	-	-	-	-	*	*
23		*Hoplodoris grandiflora*	-	-	-	-	-	*
24		*Sclerodoris tuberculata*	*	*	*	*	-	*
25	Dendrodoridae	*Dendrodoris fumata*	-	*	*	-	-	-
26		*Doriospilla miniata*	-	-	-	-	*	*
27	Tethydidae	*Melibe viridis*	-	-	-	-	*	*
28	Lomanotidae	*Lomanotus vermiformis*	-	-	-	-	*	*
29	Dotidae	*Doto sp.*	-	-	-	-	*	-
30	Bornellidae	*Bornella stellifer*	*	-	-	-	*	*
31	Arminidae	*Dermatobranchus fortunate*	*	-	*	-	-	*
32	Zephyrinidae	*Jonolus toyamensis*	-	-	-	-	-	*
33	Tergipedidae	*Phestilla lugubris*	*	*	-	-	-	-
34	Eolidae	*Sakuraeolis gujaratika*	-	-	-	-	*	*
35		*Pteraeolidia ianthina*	-	-	-	-	-	*
36		*Antaeolida foulisi*	-	-	-	-	*	-
37	Tergipedidae	*Trinchesia yamasui*	-	-	-	-	*	*
38	Glaucidae	*Phidiana militaris*	-	-	-	-	*	*

39		*Cratena capensis*	-	-	-	-	*	-
40		*Cratena peregrina*	-	-	-	-	*	*
41		*Cratena lineate*	-	-	-	-	-	*
42	Flabellinidae	*Flabellina bicolor*	-	-	-	-	*	*
43	Onchididae	*Onchidium verruculatum*	*	*	*	*	*	*
		Total Richness	**12**	**12**	**11**	**15**	**26**	**27**

Pi = Pirotan, G = Goose, N = Narara, K = Kalubhar, Po = Poshitra, A = Asaba Pir
*present

Fig: 6.8 Contribution of familes in the species richness recorded at six study locations



The Opisthobranchs fauna of GoK can be divided in four major groups (Table: 6.9).

1. Elysids: Those feeding on algae belonging this group
2. Dorids: Those which feed mainly on sedentary sponges and tunicates
3. Aeolids: Feeding on hydroids

4. Others: All other than above mentioned

Based on the IVI of these groups, elysids were found to be most dominant at Pirotan (IVI= 40.8) followed by Kalubhar (39.9), whereas maximum IVI of dorids was recorded at Kalubhar (97.5), followed by Narara and Goose IVI = 88.3 and 88.5 respectively. The Aeolids were most dominant at Poshitra with IVI = 82 followed by Asaba Pir with IVI = 63. The Aeolids were absent from Goose, Narara and Kalubhar.

Considering the species richness maximum richness of dorids are in Kalubhar with 8 species followed by Narara and Goose with 6 species each. Maximum richness of elysids were at Poshitra (6) and Asaba Pir (5), whereas maximum species richness of aeolids were recorded at Asaba Pir with 9 species followed by Poshitra 8 species.

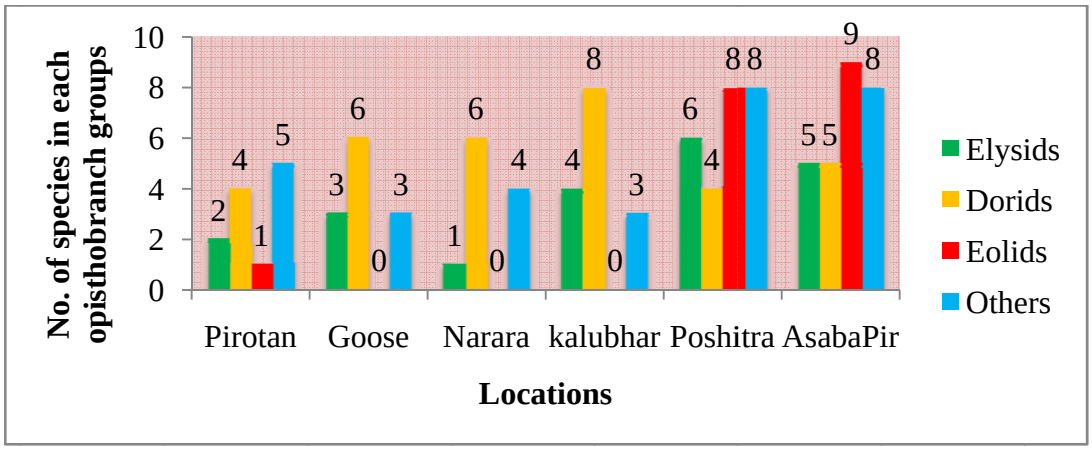
Table 6.8: IVI of major Opisthobranch groups at six locations

IVI of major groups	**Locations**					
	Pirotan	**Goose**	**Narara**	**kalubhar**	**Poshitra**	**Asaba Pir**
Elysids	40.8	39.3	33.4	39.9	17.7	6.35
Dorids	59.4	88.5	88.3	97.5	31.3	38.1
Aeolids	8.04	0	0	0	82	63
Others	46.1	39.3	62.8	45.1	43.9	57.16

Table: 6.9 No. of species of each major group of Opisthobranchs at each study location

Groups	Locations					
	Pirotan	Goose	Narara	kalubhar	Poshitra	Asaba Pir
Elysids	2	3	1	4	6	5
Dorids	4	6	6	8	4	5
Aeolids	1	0	0	0	8	9
Others	5	3	4	3	8	8

Fig: 6.9 Species richness of each opisthobranch group at study locations



Jaccard's Species Similarity Index (Table 6.10)

Maximum similarity in the opisthobranch species was recorded between Goose and Kalubhar (0.6) with seven common species *viz. Berthellina citrina, Elysia ornata, Elysia tomentosa, Tayuva lilacina, Joruna funebris, Sclerodoris tuberculata, Onchidium verruculatum* amongst them, which was equalled by Goose and Pirotan (0.6), also with seven common species (Table 6.7). This was followed by Kalubhar and Narara (0.5) having 4 common species between the two. Though 18 species were common between Poshitra and Asaba Pir (0.5), high richness at both Poshitra (26) and Asaba Pir (27) decreased the similarity between the two (0.5). Poshitra shared minimum species with other islands.

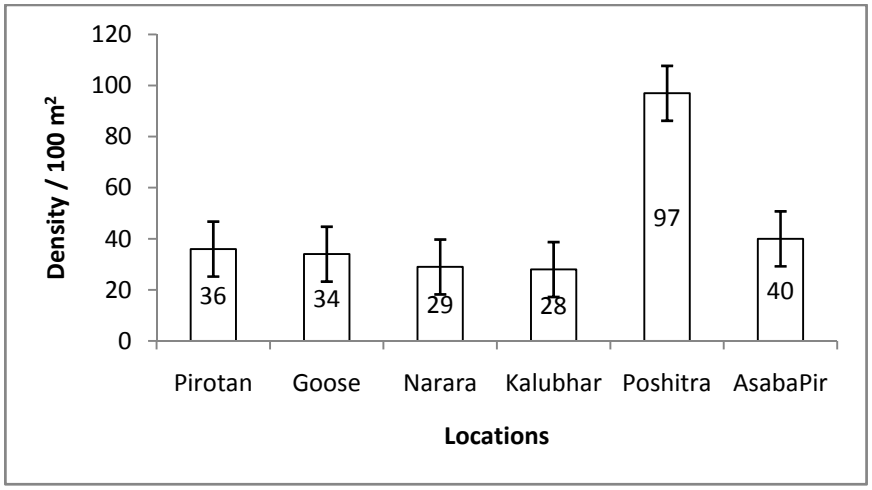
Table: 6.10 Jaccard's species similarity index for six locations (opisthobranch fauna)

Locations	Pirotan	Goose	Narara	Kalubhar	Poshitra	Asaba Pir
Pirotan	1	**0.6**	0.4	0.5	0.3	0.3
Goose		1	0.4	**0.6**	0.2	0.2
Narara			1	**0.5**	0.1	0.2
Kalubhar				1	0.2	0.2
Poshitra					1	**0.5**
Asaba Pir						1

Density of Opisthobranchs

Though being the smallest site, maximum density of opisthobranchs was observed at Poshitra (97 / 100m^2), which is significantly high ($P < 0.001$, df = 36) compared to other five locations (Fig: 6.9). This high density was due to high occurrence of Aeolids in the small patches of reef where occurrences of hydroids are also visibly high. Reefs of eastern part *viz.* Pirotan and Goose showed similar densities *i.e*. 36 and 34 / 100 m^2 respectively. Likewise in the reefs located in central gulf *viz.* Narara and Kalubhar showed similar densities *i.e.* 29 and 28 /100 m^2 respectively.

Fig: 6.10 Density of Opisthobranchs at six study locations



Species Dominance (Table 6.11)

Elysia tomentosa was the most abundant species amongst all the opisthobranchs, with maximum IVI at Pirotan (40.8), Goose (39.8) and Kalubhar (39.9) and was recorded from all the six locations. *Berthellina citrina* was dominant at Narara (IVI = 37.3), whereas *Sakuraeolis gujaratika* was dominant at Poshitra (IVI =26.8) while at Asaba Pir *Philinopsis taronga* was dominant (IVI =12.7).

Table: 6.11 IVI of the most dominant opisthobranch at each study locations

Location	Pirotan	Goose	Narara	Kalubhar	Poshitra	Asaba Pir
Species	*Elysisa tomentosa*	*Elysisa tomentosa*	*Berthellina citrina*	*Elysisa tomentosa*	*Sakuraeolis gujaratika*	*Philinopsis taronga*
IVI	40.8	39.3	37.3	39.9	26.8	12.7

Diversity Indices (Table 6.12, Fig 6.12)

An increasing trend was recorded in the Shannon-Weiner diversity Index, with 2.19 at Pirotan to 3.2 at Asaba Pir. The evenness of the data was more or less constant ranging between 0.88 to 0.9.

Fig: 6.11 IVI of the most dominant opisthobranch at study locations

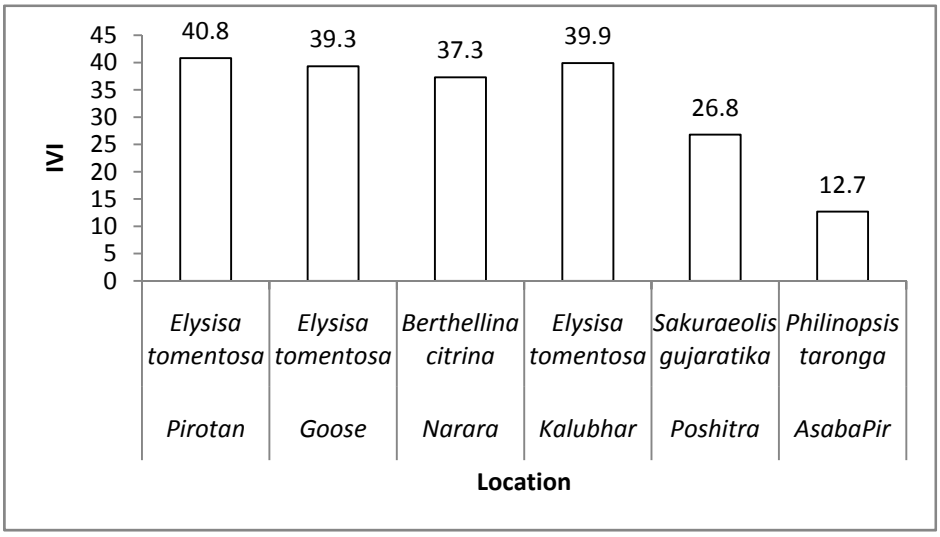
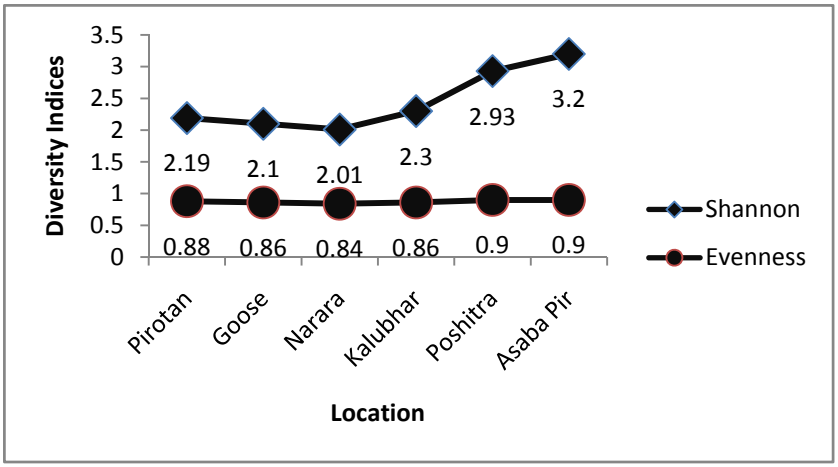


Table: 6.12: Diversity Indices of Opisthobranchs at six locations

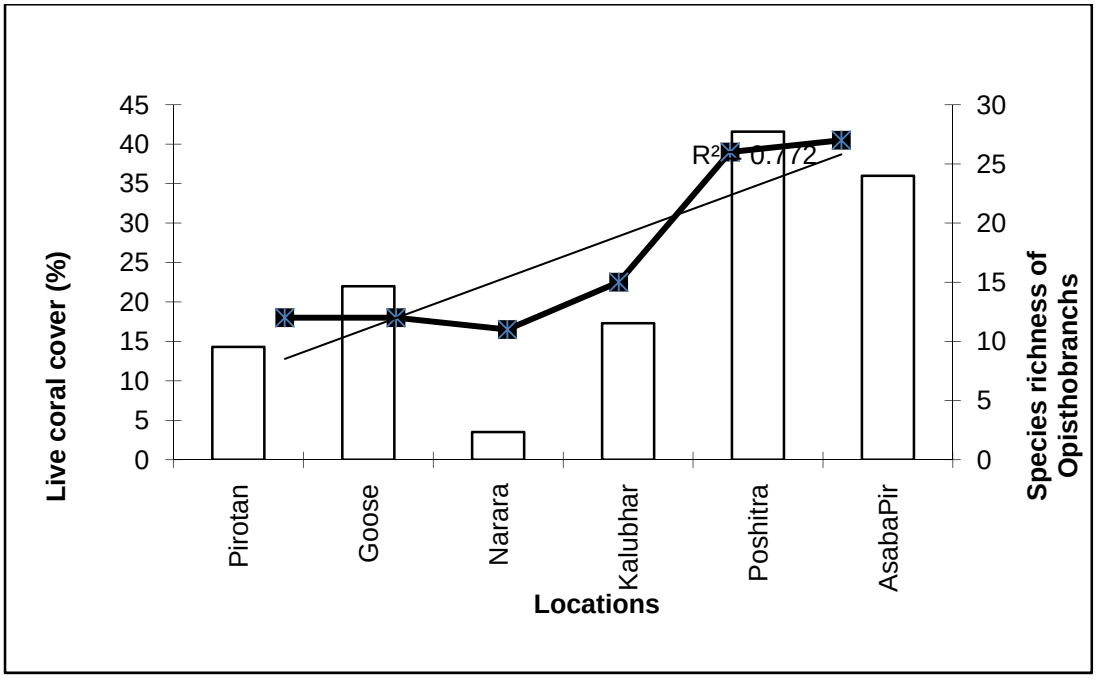
Locations	Pirotan	Goose	Narara	Kalubhar	Poshitra	Asaba Pir
Shannon	2.19	2.1	2.01	2.3	2.93	3.2
Evenness	0.88	0.86	0.84	0.86	0.9	0.9

Fig: 6.12: Diversity Indices of Opisthobranchs at six locations



When the data of average live coral cover of these reefs (Chapter 5) and the species richness of the opisthobranchs, was applied to regression, the regression value (R^2) was 0.77.

Fig: 6.13 Comparison of live coral cover (%) V/S opisthobranch Species richness



Other Associates

Poor diversity of other associates was recorded in the central and eastern reefs *i.e.* minimum at Kalubhar with 30 species followed by Goose 33 and Pirotan by 36. Maximum species richness was recorded at Poshitra with 51 species, followed by Asaba Pir with 42 species.

Table 6.13: Associated fauna (other than opisthobranchs) (Plate 6.5, 6.6, 6.7, 6.8, 6.9, 6.10

		Locations					
	Associated Fauna species	Pi	G	N	K	Po	A
	Porifera						
1	*Haliclona sp.*	*	*	*	*	*	*
2	*Calyspongia sp.*	*	*	*	*		*
3	*Suberites sp.*	*		*			
4	*Haliclona implexiformis*	*	*	*	*	*	*
5	*Galiodes sp.*		*	*	*		
6	*Cinachyrella alloclada*	*	*	*	*		
7	*Cinachyra sp*	*		*	*	*	
8	*Cliona delitrix*		*	*	*		
9	*Sigmadocia caerulea*	*	*	*	*		*
	Cnidaria						
10	*Palythoa sp.*	*	*	*	*	*	*
11	*Porpita porpita*			*		*	
12	*Pennaria disticha*	*				*	*
13	*Macrorhynchia phillipina*					*	*
14	*Savalia sp.*					*	
15	*Heteractis sp.*	*	*	*	*	*	*
16	*Stichodactyla gigantea*	*	*	*	*	*	*
17	*Stichodactyla haddoni*	*		*		*	
18	*Phyllorhiza sp.*					*	
19	*Diadumene lineata*					*	*
	Arthropoda						
20	*Atergatis integerrimus*	*				*	*
21	*Portunus pelagicus*	*	*	*	*	*	*
22	*Calappa lophos*						*
23	*Pilumnus vespertilio*	*	*	*	*	*	*
24	*Phalangipus hystrix*			*	*		
25	*Doclea sp.*	*	*				*
26	*Schizophrys aspera*	*			*	*	
27	*Thalameta integra*					*	*

28	*Periclimenes brevicarpalis*	*	*	*	*	*	*
29	*Alpheus sp.*		*			*	
30	*Metapenaeus sp.*						*
31	*Panulirus polyphagus*						*
32	*Eucine australis*	*	*	*	*	*	*
33	*Pherecardia striata*	*	*	*	*	*	*
	Mollusca						
34	*Diodora funiculata*					*	*
35	*Gibbula swainsonii*						
36	*Trochus niloticus*	*	*	*	*	*	*
37	*Lunella coronate*		*	*			
38	*Turbo intercostalis*					*	*
39	*Nerita albicilla*					*	*
40	*Nerita oryzarum*					*	*
41	*Cerithium morus*		*		*		
42	*Cerithium scabridum*		*		*		
43	*Cerithidea cingulata*			*			
44	*Telescopium telescopium*			*			
45	*Cypraea lynx*	*				*	
46	*Cypraea ocellata*	*				*	
47	*Natica picta*			*			
48	*Bursa granularis*		*	*	*	*	
49	*Bufonaria spinosa*	*		*		*	*
50	*Chicoreus ramosus*						
51	*Murex brunneus*	*	*		*	*	*
52	*Thais rugosa*	*	*		*	*	*
53	*Murex ternispina*			*	*		*
54	*Thais lacera*	*					*
55	*Cronia subnodulosa*	*				*	
56	*Nassarius olivacea*	*	*	*	*	*	*
57	*Hemifisis pugilinus*						*
58	Mitra scutulata	*				*	*
59	*Turbinella pyrum*						*
60	*C. cumnigii*		*			*	
61	*Cardium flavum*		*	*			
62	*Chiton chiton*					*	
63	*Pinna bicolor*			*			
64	*Paphia rotundata*	*				*	
65	*Scutus unguis*		*	*			
66	*Octopus vulgaris*	*	*	*	*	*	*
67	*Sepia sp.*					*	
68	*Erronea onyx*		*	*		*	

	Echinodermata						
69	*Ophioplocus imbricatus*	*	*	*	*	*	*
70	*Ophiarachna affinis*					*	
71	*Ophidiaster confertus*					*	
72	*Ocnus suspectus*					*	
73	*Laganum depressun*					*	
74	*Salmacis bicolor*	*		*		*	*
	Helminthes and other Worms						
75	*Acanthobonellia pirotanensis*	*	*	*	*		*
76	*Baseodiscus hemprichii*					*	*
77	*Maritigrella fuscopunctata*			*			
78	*Pseudoceros susanae*						*
79	*Pseudobiceros fulgor*					*	
80	*Pseudobiceros sp.*					*	*
81	*Pseudobiceros hancockanus*			*			
82	*Sabellastarie indica*	*	*	*	*		
	Total Species	**36**	**33**	**40**	**30**	**51**	**42**

* presence

6.3 DISCUSSION

Though being charismatic, due to the lack of available identification material, this group has not been properly studied throughout the world, especially in India. The region specific publications pertaining to the opisthobranch fauna are Ramakrishna *et al.* (2010), Apte *et al.* (2009; 2010) and Joshi (2011). These studies indicate the availability of the resource material for the research and the limelight given to the opisthobranchs. In the GoK, majority of the works of Narayana (1968; 1969; 1970; 1971a, b), which is considered to be the most comprehensive, were highly confined to the western part of the gulf, and also dependant on the trawl bycatch. The advancement of Information technology, the evolution of the website (www.seaslugforum.org), provided extensive information on the sea slugs, and amateurs could upload some of their records (Deomurari, 2006) in the public domain, and the inventory of opisthobranchs was improved. Of the total 43 species of opisthobranchs recorded during the present study, 7 species are re-recorded from the previous studies (Narayan, 1969; 1970). While 36 species are recorded for the first time from this study area with 22 first records for the country (Apte *et al.* 2010). *Sakuraeolis gujaratika* was first recorded from Adatra (Okha), by Rudman (1980a), and was described as type locality (Rudman, 1980a). After a gap of 40 years it was re-recorded during this study from Poshitra.

Considerable rise in the species richness of opisthobranchs was observed while moving from eastward located reefs in the gulf to the westward located reefs, as is recorded for corals too (Chapter 5). In total only 19 species were recorded from eastern and central locations *i.e.* Pirotan, Goose, Narara and Kalubhar, whereas from Poshitra and Asaba Pir 35 species were recorded, which shows significant difference in the species richness of both the regions. This supports the idea that reefs of western region of GoK are least disturbed and support diverse fauna in general. Eight species were confined to only

central and eastern reefs, *viz.* Pirotan, Goose, Narara and Kalubhar, whereas 22 species were confined to Poshitra and Asaba Pir. Such variations in the species richness can be attributed to the following reasons:

1. **Live coral coverage and the Species Richness of Opisthobranchs**

Pirotan, Goose, Narara and Kalubhar are the reefs, having low live coral cover (Chapter 5), and has been considered as degraded/ degrading reefs. These degrading habitats might be affecting the species richness of the opisthobranchs in the area. Contrarily Poshitra and Asaba Pir have recorded high live coral cover with high species richness of the opisthobranchs. The Pearson's correlation index between the live coral cover and species richness of the opisthobranchs was 0.91 ($P<0.1$), which confirms the significant correlation between the live coral cover and the species richness of the opisthobranchs in the GoK.

2. **Habitat characteristics, Availability of food and Species Composition**

Species similarity index ranging between 0.5 to 0.6 for the opisthobranchs for the four reefs *viz.* Pirotan, Goose, Narara and Kalubhar were moderately similar. However the reefs having above average coral cover (Chapter 5) *i.e.* reef of Poshitra and Asaba Pir showed low (0.5) species similarity index for among them as well as with remaining four reefs *viz.* Pirotan, Goose, Narara and Kalubhar. In other words it can be said that though two neighbouring reefs each has high diversity of opisthobranchs at species level, they are different and also different from the disturbed or deteriorating reefs of central and eastern GoK, where coral cover is also low. Hence it can be said that the species richness of the opisthobranch fauna in GoK reefs is highly associated with the status of live coral cover.

When the species richness of opisthobranchs divided in to four major groups based on their feeding habits is considered

(a) Elysids: Herbivores Feeding on algae

(b) Dorids: Carnivores Feeding on ascidians, sponges

(c) Aeolids: Carnivores feeding on hydroids

(d) Others: All the other than above mentioned groups

Elysids: This group of opisthobranchs mainly feeding on marine algae and sometimes Sea grass (Wagele, 1989) was recorded at all the six locations but with different abundance value. This manifests the availability of food at all the six sites. It was a major group of which, *Elysia tomentosa* was dominant species at three of the eastern and central reefs *viz.* Pirotan, Narara and Kalubhar, where vegetation cover was also high (Chapter 5, Fig: 5.21), but also at Goose reef where vegetation cover was comparitively low. At Narara this species was second highest in abundance, while *Berthellina citrina* was the most abundant species. This indicates that *Elysia tomentosa* is a generalist species thriving in disturbed habitats. As discussed earlier the eastern and central reefs face more disturbances then the western reefs where diversity was generally high.

Dorids: This group of carnivorous opisthobranchs mainly feed upon sedentary invertebrates such as sponges, tunicates and ascidians, the sedentary animals that require dead rocks as substrate for attachment. The already degraded site provide suitable substratum to them. Maximum diversity and IVI of this group was recorded at Kalubhar (8, 97.5), followed by Narara and Goose (6 species each with IVI 88.5 and 88.3 respectively). When rock and rubble cover of these reefs are considered, non-significant correlation could be noted at Narara and Kalubhar, which are more under anthropogenic stress due to industrial activities.

Aeolids: This group has special adaptation for feeding upon stinging hydroids. Such hydroids can grow in the healthy coral reefs only (Lambert, 1991). Maximum diversity of this group was recorded at Asaba Pir (9), followed by Poshitra (8 species), where live coral cover is also recorded high. At Pirotan only 1 species of eolid was recorded, while other three reefs of eastern and central zone *viz.* Goose, Narara and Kalubhar were devoid of any population of this group, again supporting the theory that eastern and central reefs are under heavy pressure of degradation.

Reef associated fauna other than the opisthobranchs, justifies the disturbance in the central regions, by the presence of species such as *Cerithidea cingulata* and *Telescopium telescopium*, which are the indicators of Muddy / degrading habitat, whereas presence of *Ophidiaster confertus* and *Lamprometra sp*. indicates healthy conditions at Poshitra.

Hence it can be concluded that the species richness of opisthobranch fauna with other associates in the GoK is associated to the habitat / reef health, which is directly correlated to the availability of food source. From the abundance of certain groups of opisthobranchs it may be indicated that the health status of the reef of Poshitra and Asaba Pir is good due to presence of Aeolids that indicate healthy reef, while that of other reefs are facing some stress as indicated by presence of dorids as they indicate degraded reefs.

Plate 6.1: Ophisthobranchs recorded at six study locations

Elysia ornata

Elysia tomentosa

Elysia thompsoni

Lobiger viridis

Oxynoe panamensis

Berthelina citrina

Dermatobranchus fortunata

Plocamopherus ceylonicus

Plate 6.2: Ophisthobranchs recorded at six study locations

Tayuva lilacina

Jorunna funebris

Sclerodoris tuberculata

Doriospilla miniata

Hypselodoris sagamiensis

Hypselodoris infucata

Hypselodoris carnea

Peltodoris murrea

Plate 6.3: Ophisthobranchs recorded at six study locations

Bornella stellifer

Janolus toyamansis

Cratena peregrina

Flabellina bicolor

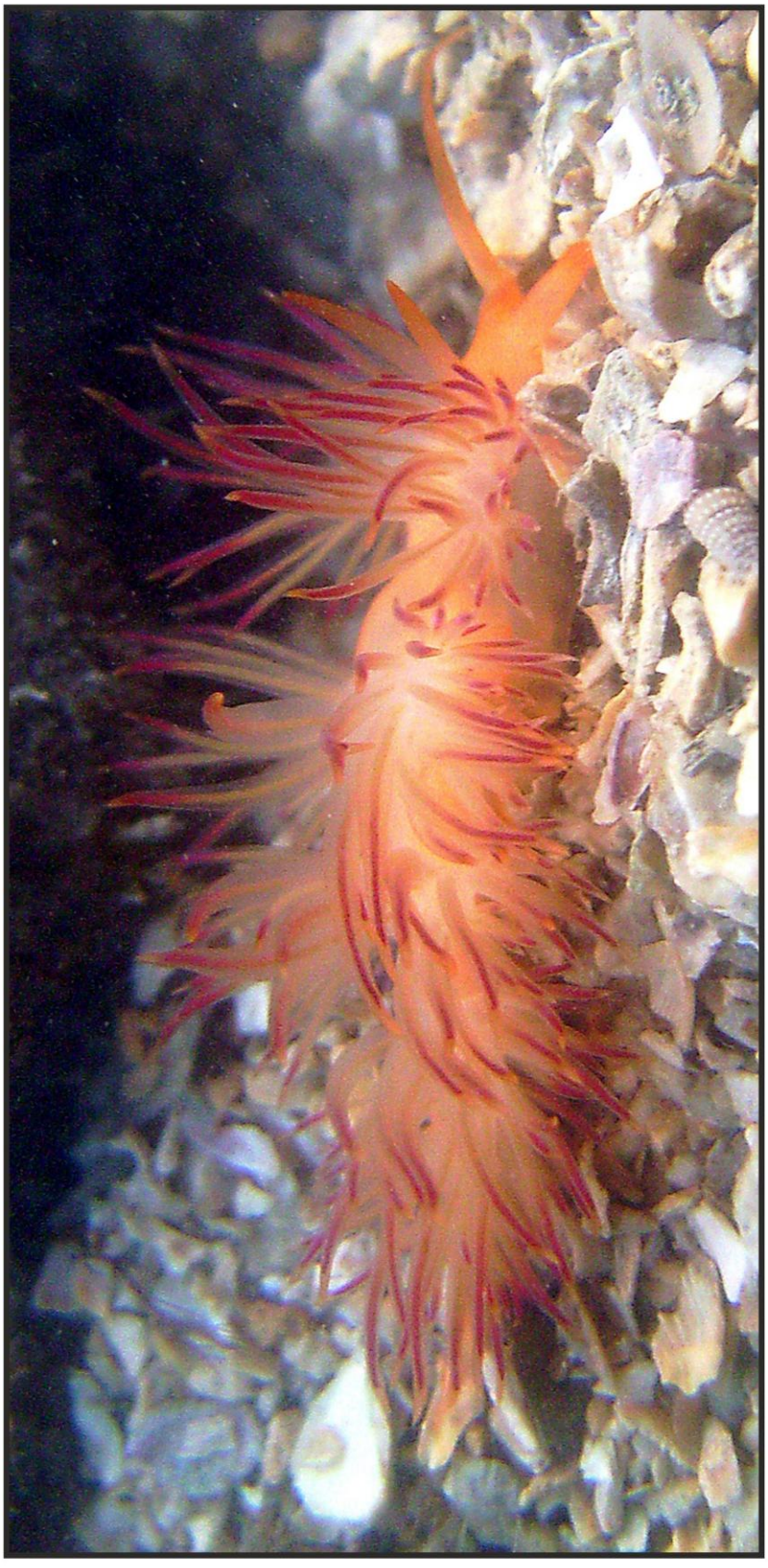
Lomanotus vermiformis

Pteraeolidia ianthina

Cuthona yamasui

Phidiana militaris

Plate 6.4: Ophisthobranchs recorded at six study locations



Sakuraeolis gujaratica

Plate 6.5: Other Mollusca recorded at six study locations

Pinna bicolor

Paphia rotundata

Turbinella pyrum

Erronea onyx

Diodora funiculata

Chiton chiton

Scutus unguis

Octopus vulgaris

Plate 6.6: Porifera recorded at six study locations

Haliclona sp.

Callyspongia sp.

Suberites sp.

Cliona delitrix

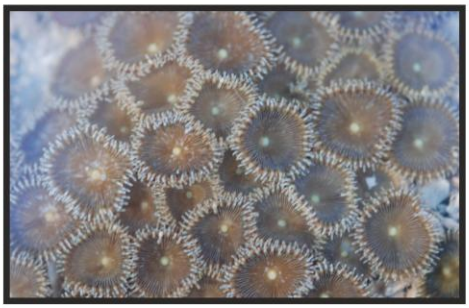
Galiodes sp.

Haliclona implexiformis

Cinachyrella alloclada

Cinachyra sp.

Plate 6.7: Cnidaria recorded at six study locations

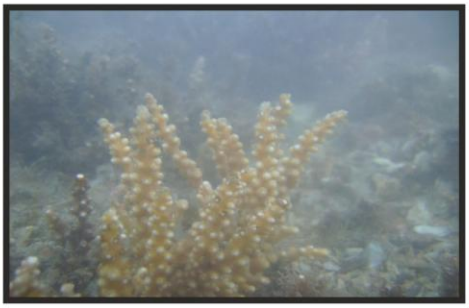


Palythoa sp.

Porpita porpita

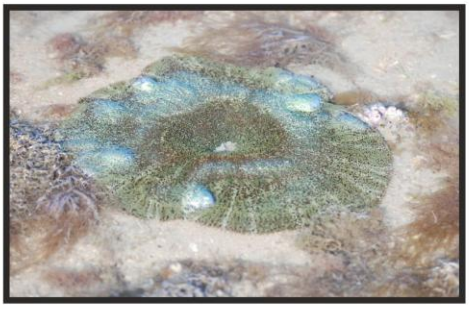
Pennaria disticha

Macrorhynchia philippina



Savalia sp.

Heteractis sp.



Stichodactyla haddoni

Stichodactyla gigantea

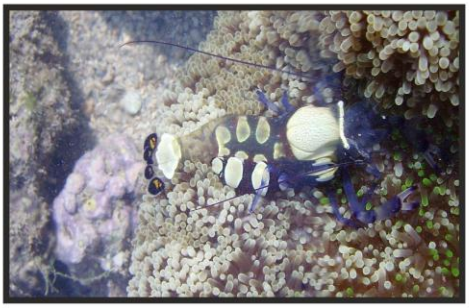
Plate 6.8: Arthropoda recorded at six study locations

Atergatis integerrimus

Portunus pelagicus

Calappa lophos

Pilumnus vespertilio



Periclimenes brevicarpalis

Alpheus sp.

Eucine australis

Pherecardia striata

Plate 6.9: Echinodermata recorded at six study locations

Ophioplocus imbricatus

Ophiarachna affinis

Ophidiaster confertus

Ocnus suspectus

Lamprometra sp.

Holothuria scraba

Laganum depressun

Salmacis bicolor

Plate 6.10: Worms recorded at six study locations

Acanthobonellia pirotanensis

Baseodiscus hemprichii

Maritigrella fuscopunctata

Pseudoceros susanae

Pseudobiceros fulgor

Pseudobiceros sp.

Pseudobiceros hancockanus

Sabellastarie indica

7. WATER QUALITY

CHAPTER 7
MARINE WATER ANALYSIS

7.1 INTRODUCTION

The marine hydrography is much complicated due to the dynamic nature of the ecosystem. Changes in the hydrographical parameters such as salinity, dissolved oxygen, dissolved carbon dioxide; nutrients, *etc.* affect the activities and growth of the organisms in this ecosystem (Sridhar *et al.* 2008). Good quality of water resources depends on a large number of physicochemical parameters and the magnitude and source of any pollution load. Monitoring of these parameters is essential for the survival of species (Reddi *et al.*, 1993). The, developmental activities of a region depend on various resources of water such as rivers, lakes and man-made reservoirs that supply water for domestic, industrial, agricultural needs (Jakher and Rawat, 2003). As far as corals are concerned, marine water quality is one of the key factors, which determines the extent of the health of the reef. The coral reefs at global level are largely confined to the warmer tropical waters. Healthy growth of corals require that Physico-chemical factors of marine water such as temperature (to be between 22^0C to 32^0C), salinity (32 to 36 ppt), turbidity, pH, nutrients, light, *etc.* remain in certain range.

Site-specific measurements have been carried out in the Gulf of Kachchh for various industrial projects for the last several years. But literature review shows that studies relating to the GoK marine environment are very limited. Tides and tidal currents in the Gulf have been studied by Unnikrishnan *et al.* (1999), Shetye (1999) and Vethamony *et al*. (2004) to understand the tidal amplification and resonance and role of tidal eddies in pollutant transport. The geological aspects of the Gulf and its environment have also been studied to a certain extent, but studies of these parameters in relation to

biological aspects including intertidal benthos and coral reefs are very limited. No reef specific study has been carried out so far, which measures Temperature, pH, DO, Salinity and Turbidity of water that bathe various reefs in the gulf.

In the era of industrial development, when loads of pollution in varied forms is added to water, marine water is no exception. At GoK also the development of industries at both the coasts with increased movements of vessels is expected to increase the pollution, which in turn can affect coral diversity.

In order to carry out sustainable development along the GoK it is necessary to plan industrialization in a controlled manner. One way of doing this is by zoning the area based on various water uses. In any coastal segment, the coastal water is subjected to several types of uses. Among these there would be a use that may be considered as designated best use, controlling the quality of water in that stretch. The Central Pollution Control Board (CPCB) of India has set criteria for classification and zoning of coastal waters into five categories: SW1, SW2, SW3, SW4 and SW5 based on the designated best use of these waters. The uncontrolled discharge of organic matter in coastal regions causes anoxic conditions (Desa *et al.* 2005). With this background it was felt necessary to analyse the quality of water at six reefs, for the most important parameters for survival of corals like temperature, pH, Salinity, DO and turbidity.

Single point sampling was carried out at the low tide point of the reef, during the receding tide. Sample was then analysed *in-situ* using standard water analysis kits (Chapter 4). Three seasons were followed, *i.e.* winter, post winter and summer, with replication for winter and post winter in the second year.

7.2 RESULTS

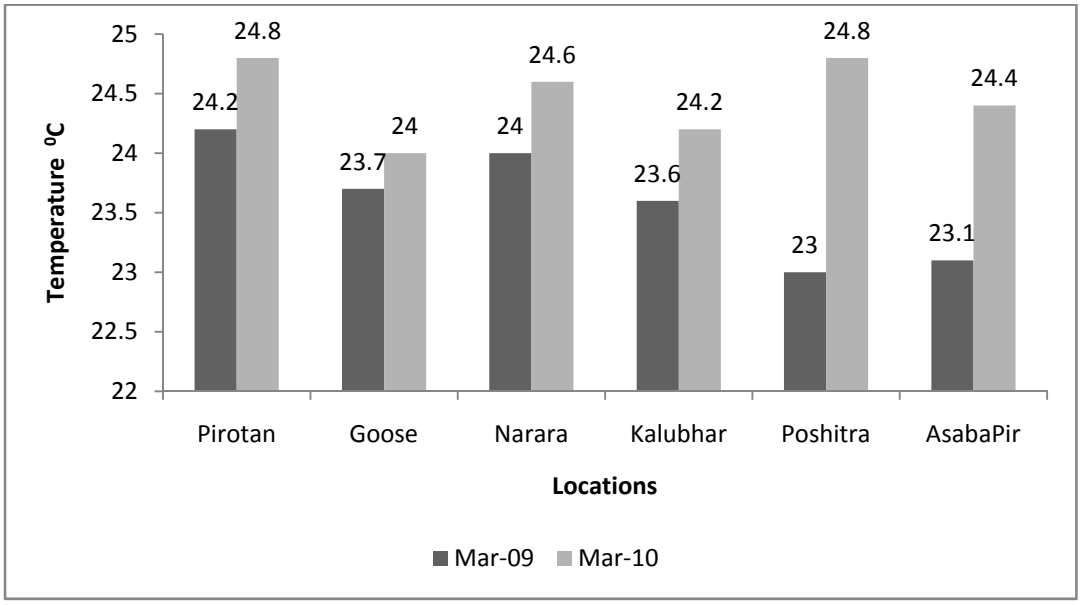
Temperature (Table: 7.1, Plate: 7.1)

The water temperature varied seasonally. Maximum variations were recorded at Goose, between minimum 23^0C in November 2008 to maximum 34^0C during May 2009, whereas lowest variations were noted at Asaba Pir between minimum 22^0C during November 2008 and maximum 25.2^0C in May 2009. Hence the temperature range in the southern GoK may be considered from minimum 22^0C to maximum 34^0C. However, the temperatures of November 2009 and March 2010 showed higher values compared to November 2008 and March 2009. Maximum difference was noted in the two year temperatures at Poshitra, where in March 2009 the water temperature was 23^0C, compared to March 2010 when it was 24.8 ^{0}C, *i.e.* difference of 1.8^0C (Fig 7.1).

Table: 7.1: Water temperature (^{0}C) at six study locations

Season	Location					
	Pirotan	**Goose**	**Narara**	**Kalubhar**	**Poshitra**	**Asaba Pir**
Nov-08	23	23	23.5	23.4	22	22.4
Mar-09	24.2	23.7	24	23.6	23	23.1
May-09	26.8	34	30	28	25.2	25.4
Nov-09	23.5	22.8	23.7	23.7	23.3	22.8
Mar-10	24.8	24	24.6	24.2	24.8	24.4

Fig: 7.1 Temperature variations between March 2009 and March 2010 at study locations



pH (Table 7.2, Plate 7.2)

The pH of the southern GoK water was basic (> 7.0) at majority of the sites. Maximum pH was recorded during May 2009 (pH =8.4) at Goose and lowest during November 2008 (pH = 6.8) at Narara. Hence the range of pH in the gulf can be considered between 6.8 to 8.4. During all the seasons the pH values at Poshitra, Asaba Pir and Goose recorded comparatively higher values than the other reefs of the eastern and central gulf *i.e*. Pirotan, Narara and Kalubhar. Narara recorded lowest pH throughout the study. The difference between summer and winter pH was 0.5 to 0.6 at all the reefs.

Table 7.2: pH at six study locations

Season	Locations					
	Pirotan	**Goose**	**Narara**	**Kalubhar**	**Poshitra**	**Asaba Pir**
Nov-08	7.1	7.9	6.8	7	7.8	7.7
Mar-09	7.3	7.9	6.9	7.2	8	8
May-09	7.6	8.4	7.2	7.5	8.3	8.2
Nov-09	7.2	7.8	7	7.1	7.7	7.9
Mar-10	7.5	8.2	7.3	7.5	8.1	8.2

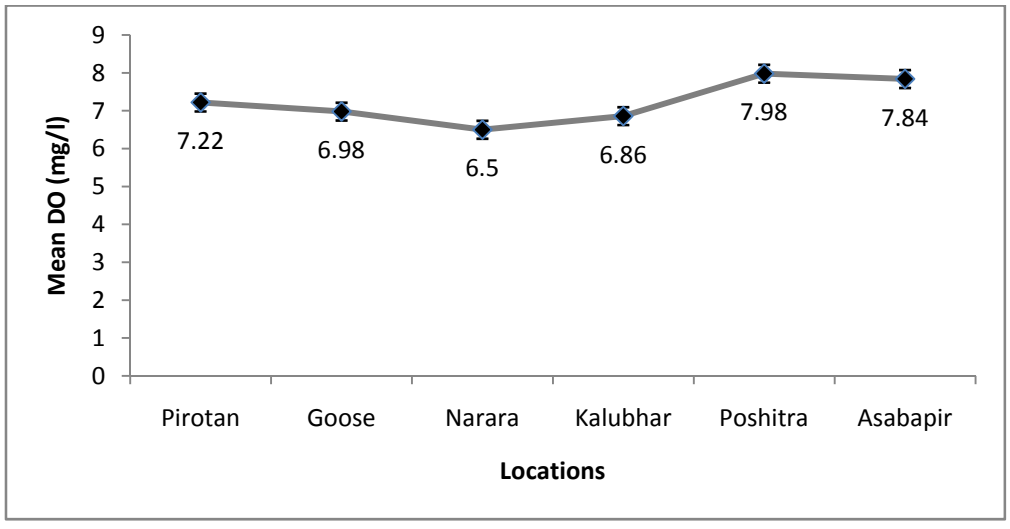
Dissolved Oxygen (Table 7.3, Plate 7.3)

Maximum dissolved oxygen content were recorded during November 2008 from Poshitra (8.5 mg/l) and Asaba Pir (8.3 mg/l), whereas lowest from Narara (5.8 mg/l) during May 2009. Hence the range of dissolved oxygen recorded was between 5.8 to 8.9 mg/l. A significant increasing trend was observed in the values of dissolved oxygen while moving from eastward located reefs to the westward located reefs.

Table 7.3: Dissolved Oxygen at six study locations

	Locations					
Season	**Pirotan**	**Goose**	**Narara**	**Kalubhar**	**Poshitra**	**Asaba Pir**
Nov-08	7.7	7.8	7	7.3	8.5	8.3
Mar-09	7.2	7.4	6.6	6.8	8	7.9
May-09	6.9	6.4	5.8	6.3	7.6	7.7
Nov-09	7.5	6.9	6.8	6.9	8.2	7.8
Mar-10	6.8	6.4	6.3	7	7.6	7.5

Fig 7.2 Mean Dissolved (± SE) Oxygen at study locations



Salinity (Table: 7.4, Plate 7.4)

Maximum salinity was recorded during May 2009 (39 ppt) at Narara whereas lowest was recorded during November 2009 at Pirotan (36.3 ppt). Hence the salinity range of marine water in GoK can be considered between 36.3 to 39 ppt. No significant difference from eastern reefs to western reefs was noted.

Table 7.4: Salinity at six study locations

	Location					
Season	**Pirotan**	**Goose**	**Narara**	**Kalubhar**	**Poshitra**	**Asaba Pir**
Nov-08	36.6	37	37.1	36.9	36.7	36.7
Mar-09	37	37.4	38.2	37.3	36.9	37
May-09	37.8	38.7	39	38.2	37.2	37.5
Nov-09	36.8	37.1	37.5	37.3	36.9	37
Mar-10	37.3	38	38.4	38	37	37.3

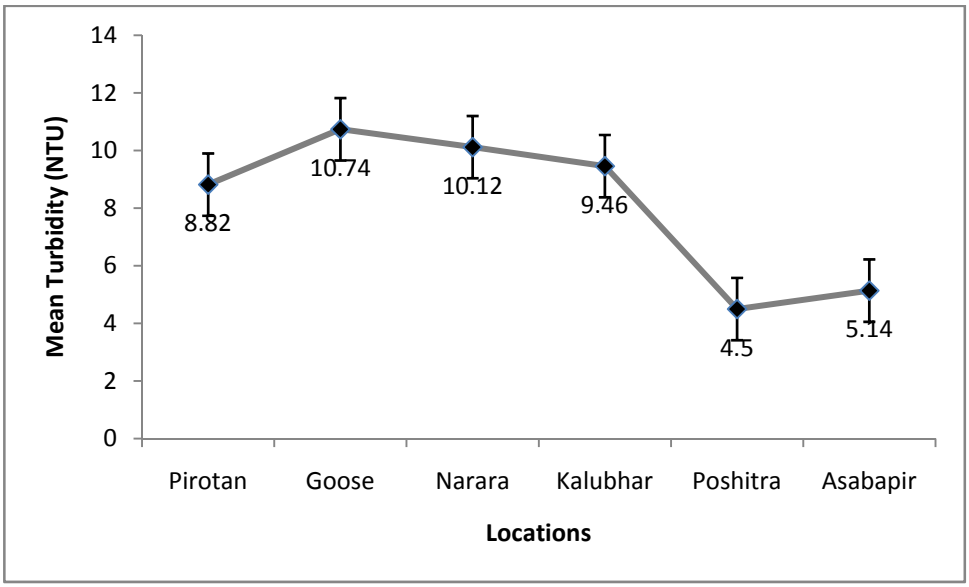
Turbidity (Table 7.5, Plate 7.5)

Maximum turbidity was recorded at Goose (10.2 to 11.4 NTU) during November 2009, whereas lowest was recorded at Poshitra (4.1 to 5.0 NTU) during March and May 2009. Hence the turbidity range recorded was 4.1 to 11.4 NTU. The difference between the maximum and minimum values ranged between minimum 0.6 to maximum 1.2 at Goose with other locations showing difference of 0.9 or 1 NTU. Significantly decreasing trend was recorded while moving from eastward located reefs to the westward located reefs.

Table 7.5: Turbidity at six study sites

Season	Locations					
	Pirotan	**Goose**	**Narara**	**Kalubhar**	**Poshitra**	**Asaba Pir**
Nov-08	9	11	10.2	9.7	4.6	5.2
Mar-09	8.7	10.6	10	9.1	4.1	5
May-09	8.3	10.2	9.8	9	4.1	4.9
Nov-09	9.3	11.4	10.7	9.9	5	5.5
Mar-10	8.8	10.5	9.9	9.6	4.7	5.1

Fig: 7.3 Mean Turbidity (± SE) at Study locations



COMPARITIVE ANALYSIS OF WATER PARAMETERS AT SIX LOCATIONS (Table 7.6) (Plate 7.1, 7.2, 7.3, 7.4 and 7.5)

Maximum mean water temperature was noted at Goose (24.46 ± 1.48 ^{0}C), whereas lowest at Asaba Pir (23.62 ± 1.25 ^{0}C). Similarly Maximum pH was recorded at Goose (8.04 ± 0.3) and lowest at Narara (7.04±0.2). Values of Dissolved Oxygen were maximum at Poshitra (7.98±0.39) and lowest at Narara (6.5±0.47), while salinity was maximum at Narara (38.04±0.75) followed by Goose (37.64±0.71) and lowest at Poshitra (36.94±0.18).

Turbidity was maximum at Goose (10.74±0.47) followed by Narara (10.12±0.36) and lowest at Poshitra (4.5±0.39).

Table 7.6 Mean Temperature, pH, DO, Salinity and Turbidity (± SD) at six locations

Locations	Temperature (0C)	pH	DO (mg/l)	Salinity Ppt	Turbidity NTU
Pirotan	24.46±1.48	7.34±0.2	7.22±0.38	37.1±0.47	8.82±0.37
Goose	25.5± 4.78	8.04±0.3	6.98±0.62	37.64±0.71	10.74±0.47
Narara	25.16±2.74	7.04±0.2	6.5±0.47	38.04±0.75	10.12±0.36
Kalubhar	24.58±1.93	7.26±0.2	6.86±0.36	37.54±0.54	9.46±0.39
Poshitra	23.66±1.32	7.98±0.2	7.98±0.39	36.94±0.18	4.5±0.39
Asaba Pir	23.62±1.25	8±0.2	7.84±0.3	37.1±0.31	5.14±0.23

Highlighted cells shows maximum value of the parameter

7.3 DISCUSSION

Most of the Physicochemical analysis of the marine water in the GoK is confined to some EIAs for the Industries to be established on the mainland. Most recent of them were carried out by NIO for ESSAR Oil (2000) and Sea King Infrastructure for the Poshitra Port development (1998). All these EIAs are not available in public domain and hence it is difficult to compare the stautus of water quality with past studies.

The Arabian Sea including the GoK is an area of negative water balance (SenGupta and Deshmukhe, 2000), where evaporation exceeds the sum of precipitation, which generally indicates hyper conditions for corals (except for the sedimentation load) i.e. high salinity and high temperature conditions (Nair 20002). Range of water temperature recorded (22^0C to 34^0C), in the present study shows great variations in the temperature. Such variations have not been reported from the other major reefs of India.

One of the major factors affecting the coral health is presence of nutrients. However due to certain limitations, the data collection on nutrients such as Nitrates, Nitrites, Phosphates *etc.* was not possible, though secondary data has been used to determine some correlation. The NO^{-3} level in the Poshitra area, was 2.83 µ mol at surface level and 2.95 at bottom level-1.26 µ mol (Anon 1997), which is quite low considered to the other reef areas of the GoK. Reef of Poshitra and reef of Asaba Pir belong to these areas. The highest values of NO^{-3} were observed at Pirotan cluster (Anon 1997), where the surface value is 4.89 µ mol and the bottom value is 5.55 µ mol (Anon 1997). The higher values of Dissolved Oxygen (DO) helps to oxidise the nitrates, nitrites and ammonia fast (Lapointe *et al.* 1997), and at Poshitra and Asaba Pir the DO values are 7.98 and 7.84 mg/l subsequently might have helped in good oxidation of nutrients, facilitate better growth of corals. The land heats up faster and cools down slowly than the water. The land on both

the sides (North and South) of GoK falls in the arid and semi arid zone of Indian subcontinent, where temperature ranges from 2^0C of winter to 45^0C in summer. The rivers in Kachchh are seasonal and dry. Major area on north of GoK is covered by two ranns i.e. Little and Greater with central portion of rocky upland, Banni plains. North of this land lies Thar Desert. Heating of these land masses with hot Arabian Desert create low pressure zones which pool the south-west monsoon wind to the mainland of Indian subcontinent. Similarly the southern coast is characterised by hot summer and dryness in the non-raining seasons where temperature fluctuates between 12.2^0C of winter to 41^0C of summer. Thus, the wind blowing from both the directions is likely to warm up GoK waters. In addition extensive movement of vessels in the Gulf, rather than allowing water to cool, is likely to add warm water to the same increasing water temperature of GoK. However these are the water to which varied fauna (Hornell, 1909) have adapted over thousands of years.

A difference recorded in the mean temperature of March 2009 and March 2010 in the follow up trips, between two years was 1^0C higher in the latter. This observation corresponds to the International bleaching event appeared during the year 2010 (Krishnan *et al.* 2010). Such bleaching is mainly caused due to the elevation in the Sea surface temperatures. Increase in temperature to 1-2 ^{0}C above the long-term average for one to two weeks is known to trigger bleaching, causing corals to turn white due to the loss of the symbiotic zooxanthellae (Hoegh, 1999; Loya *et al.* 2001). However past studies (Arthur, 2000; Krishnan *et al.* 2011) indicate that the corals of GoK are resilient to such variations. In other words, the corals of GoK have gradually adapted to the temperature variations in the marine waters of GoK, and hence there was no significant coral mortality was observed during the bleaching event caused due to elevated temperatures in recent past *i.e.* March 2010.

Atkins (1992) established pH of the water as indispensable factors for all hydrographical studies. The pH of sea water generally ranges from 7.5 to 8.4, and is slightly alkaline (Nair and Thampy, 1980). The pH range of the Gulf water between 7.1 to 8.3 is within the range expected for the coastal tropical seas. However Nair (2002) reported the pH of the gulf to be constant at 7.9-8.2. This range of pH indicates presence of corals in GoK (Nair, 2002).

There are no specific values of dissolved oxygen which are standardised for the sea water, however for the ecologically sensitive marine areas the minimum Dissolved Oxygen value has been standardised as 5 mg/l by CPCB (Anonymous 1993). The Dissolved Oxygen in water which is available to aquatic organisms is one of the most important indicators of the condition of a water body. Concentrations below 5 mg/l are stressful and may be lethal to many fish and other species (Desa *et al.* 2005). Dissolved oxygen levels in seawater column are related to several other factors such as temperature, salinity, wave action, density of planktons, pollution and the influence of external water masses (Sivasamy, 1990). The dissolved oxygen is known to decide the suitability of aquatic ecosystems to support the survival and growth of aquatic organisms. In the present study, all the study sites DO ranged between above average to rich concentrations between 5.8 to 8.9 mg/l. However it showed a significant debt in the waters of central gulf *i.e.* at Narara and Kalubhar reefs, the most disturbed reefs of the GoK. Whereas, Poshitra and Asaba Pir had higher DO compared to other four reefs. Comprehensive scientific research was carried out to analyse Dissolved Oxygen in the GoK by Desa *et al.* (2005). Criteria suggested by CPCB for the minimum DO level for any marine ecologically sensitive area is 5 mg/l. DO levels at the central gulf *i.e.* in Narara and Kalubhar with only 1.5 mg/l higher than minimum prescribed signifies highly disturbed area. The pollution load is likely to be high in the central gulf, where several mega industries are present. The

movements of vessels being higher, the turbidity in the area is also high with higher temperature. At higher temperature, water holds less Dissolved Oxygen (Desa *et al.* 2005). No correlation between DO of water and % vegetation cover (Chapter 5) indicate that other factors are also involved in influencing oxygen levels in the water. The western gulf has very stable conditions with almost 2 mg/l higher DO than the minimum required levels.

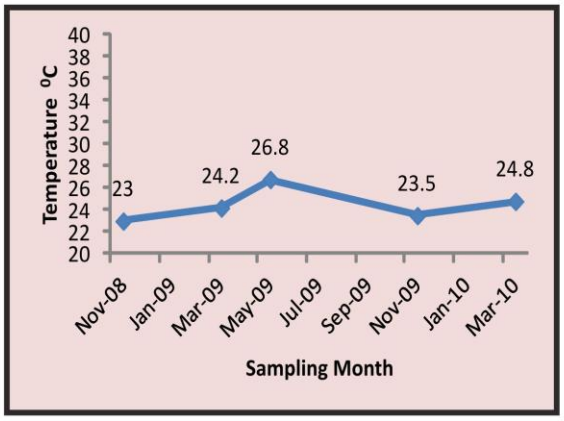
Turbidity is directly correlated with the light penetration, which is the key factor for deciding vertical distribution of scleractinian corals. GoK water as mentioned earlier has heavy sedimentary load and hence has more turbid waters compared to any other coral reefs of the country. The width of GoK decreases from the central gulf with change in the coastal orientation too, and forms a dynamic barrier across Sikka and Mundra. This indicates that majority of sediments might be facing a whirlpool effect near Sikka. Goose reef where highest turbidity was recorded is closest to Sikka. Mud cover at upper strata of Goose was 34.2% highest amongst all sites studied (Chapter 5).

Average sea water salinity is considered to be 35 ppt (parts per thousand). However the average salinity of GoK is much higher sometimes reaching to 40 ppt (Pandey *et al.* 2010). The salinity of coastal and offshore environment is influenced by a number of factors such as runoff, precipitation, evaporation, surface current patterns and upwelling (Bruckner and Burrows, 2005). Coral reefs are normally found in areas with salinities of 32 to 40 ppt. Salinity fluctuations are key factor determining local zonation patterns of corals. Rapid decrease in the salinity after monsoon rains or rates of evaporation experienced outside the normal range in a particular environment can create conditions that fail to sustain corals. Such rise in salinity was observed during the study. Narara being a coastal reef, salinity in November 2008 was 37.1 ppt, which increased to 39 ppt in May 2009, *i.e.* difference of 1.9 ppt in six months, which indicates a marked rise in salinity

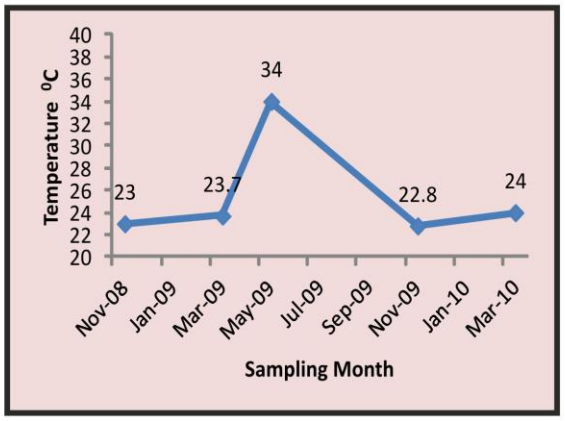
values during the Post Winter to Summer period (March to June) and lowering from Monsoon to Winter (July to December). The high salinity observed during the Summer (May 2009) in the present study might be due to the evaporation of surface water and high temperatures (Plate 7.1) around gulf.

To summarise, all the parameters observed for the marine water of GoK, were well in range, which ultimately favour the growth of coral reef ecosystem. However, signs of degradation were evident in the central and eastern gulf through remarkable low DO and pH, high temperature and turbidity and high salinity fluctuations. These water qualities also give justification to the theory that the reefs of central and eastern parts of GoK are under heavy pressure and facing severe degradation.

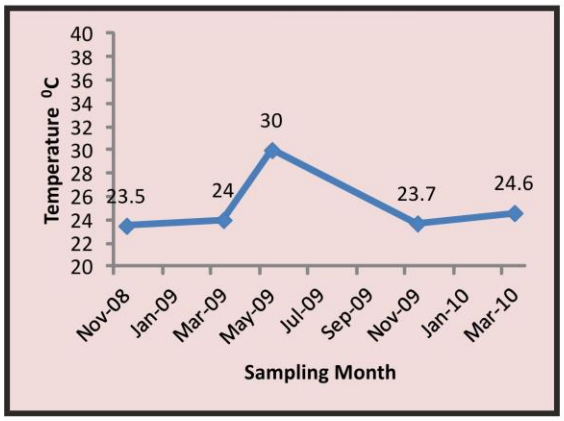
Plate 7.1. Water Temperature (Cº) at Study Locations



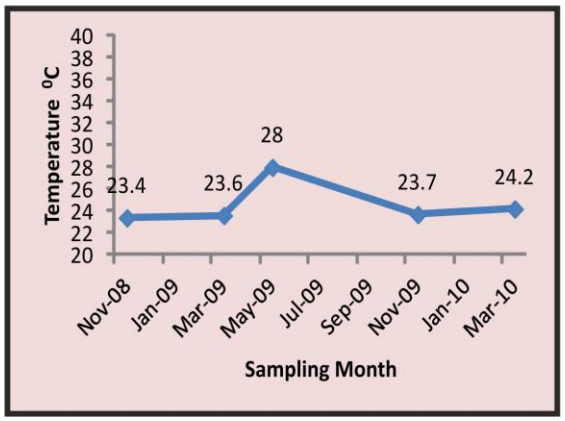
Pirotan



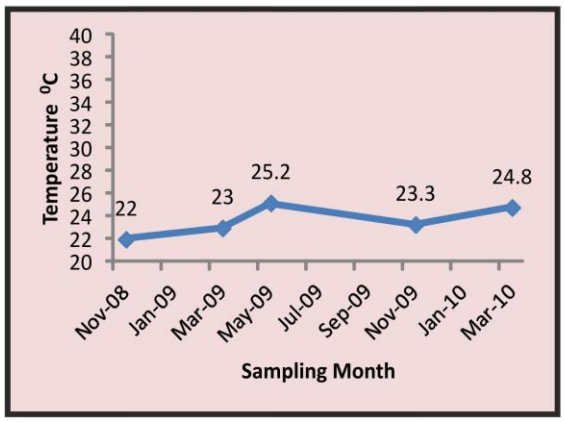
Goose



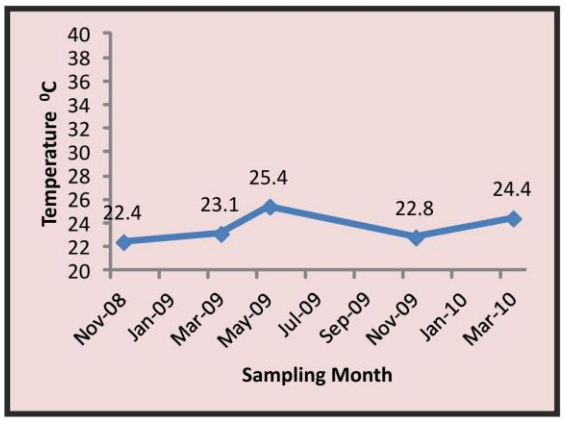
Narara



Kalubhar

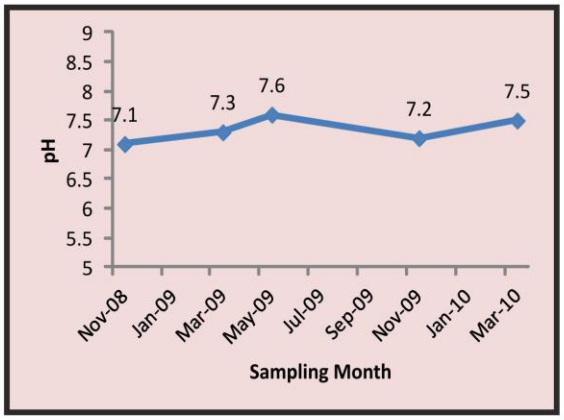


Poshitra

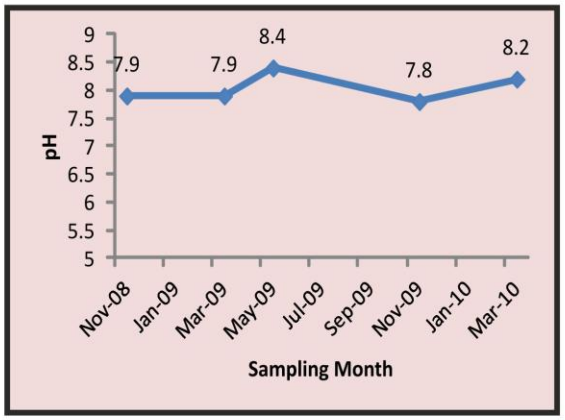


Asabapir

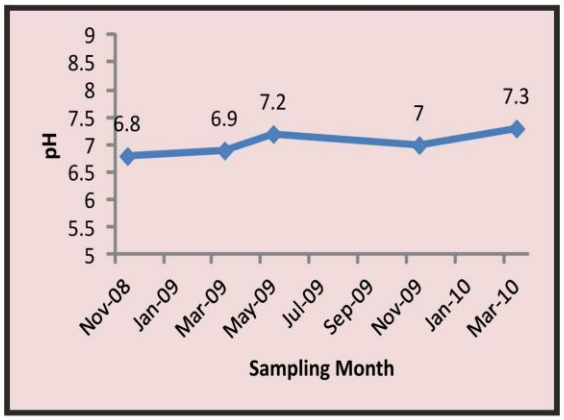
Plate 7.2. Water pH at Study Locations



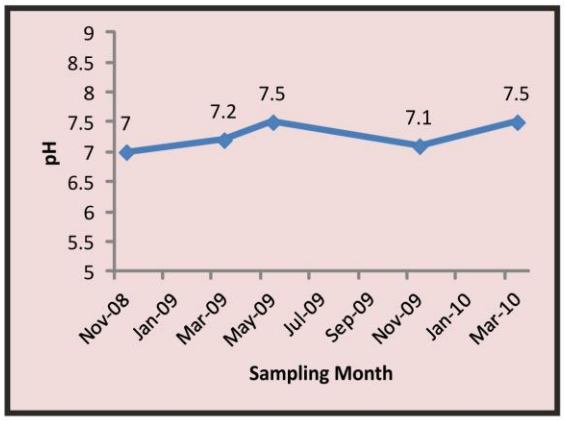
Pirotan



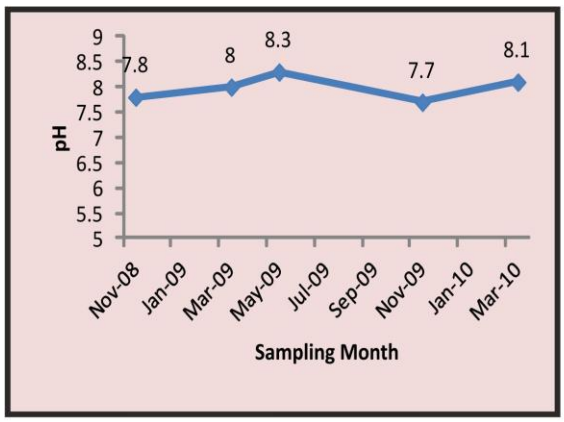
Goose



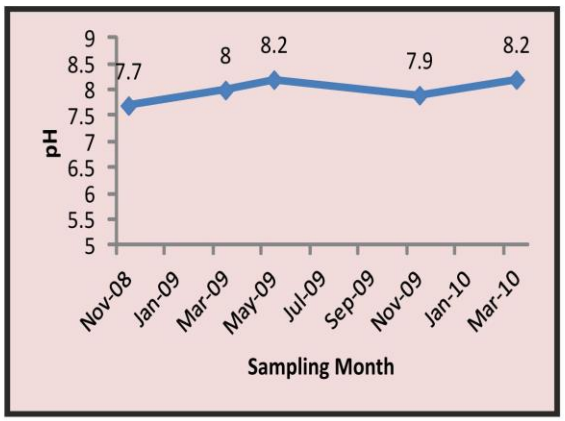
Narara



Kalubhar

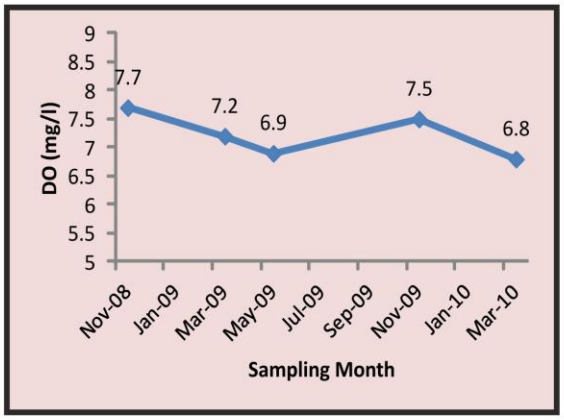


Poshitra

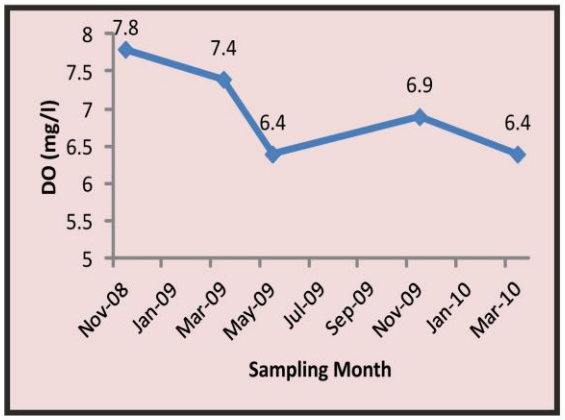


Asabapir

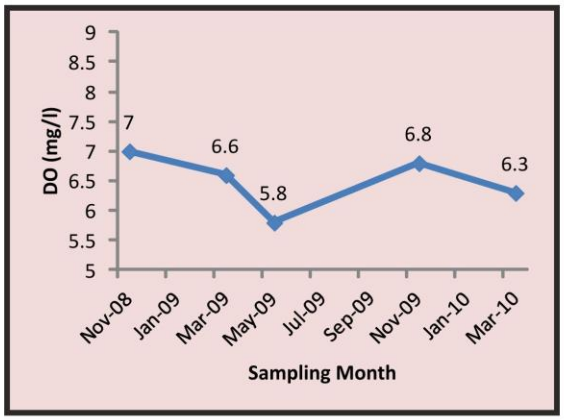
Plate 7.3. Dissolved Oxygen (mg/l) at Study Locations



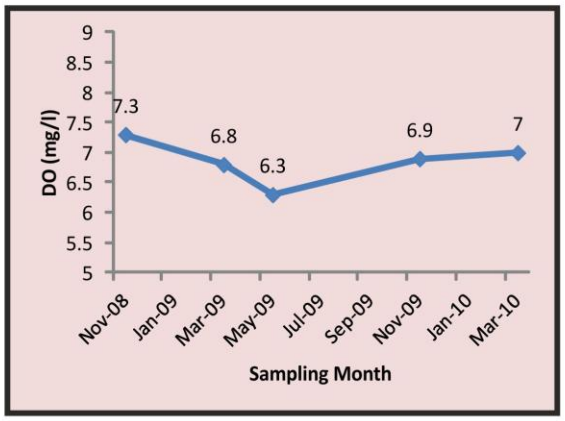
Pirotan



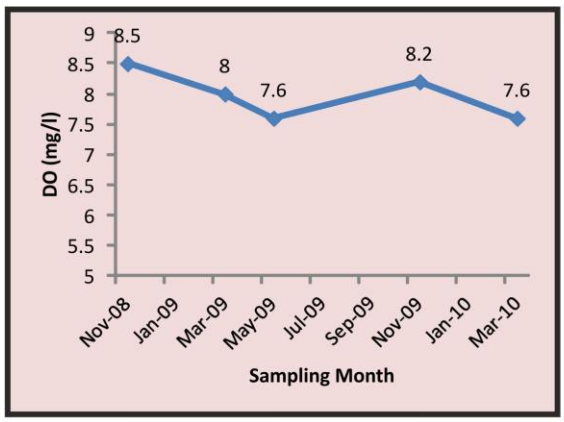
Goose



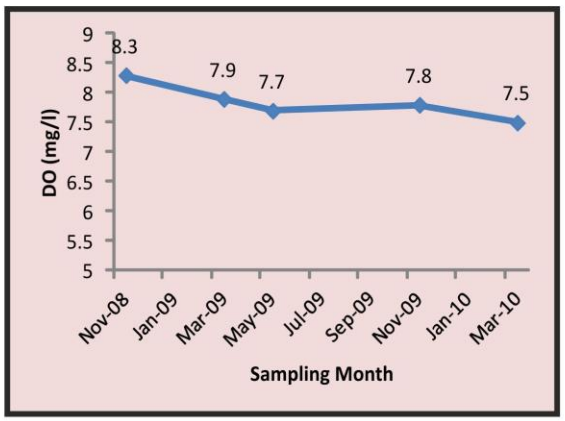
Narara



Kalubhar

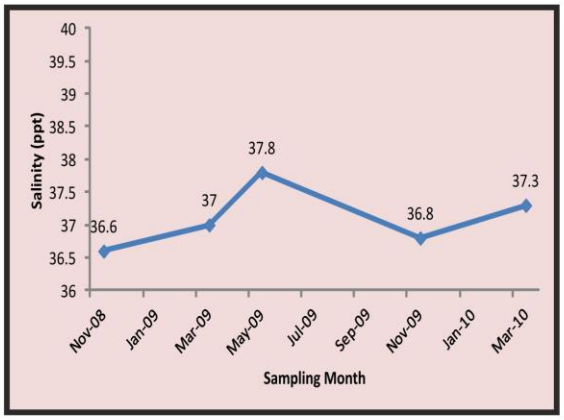


Poshitra

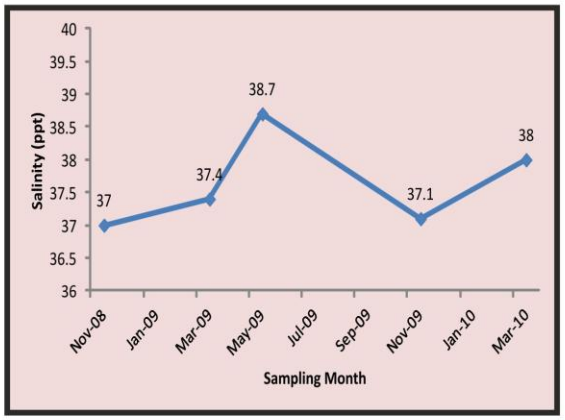


Asabapir

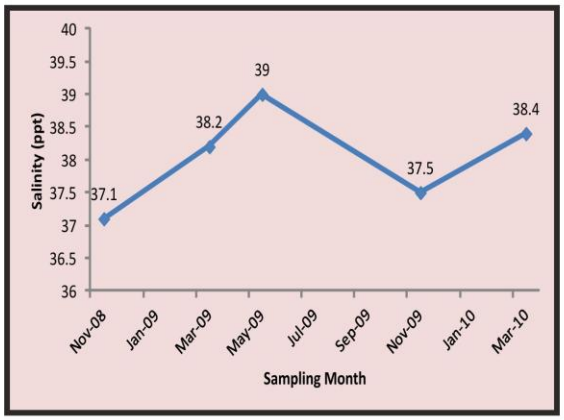
Plate 7.4. Water Salinity (ppt) at Study Locations



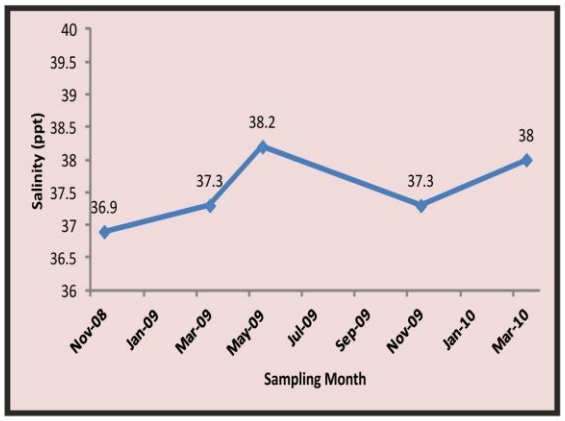
Pirotan



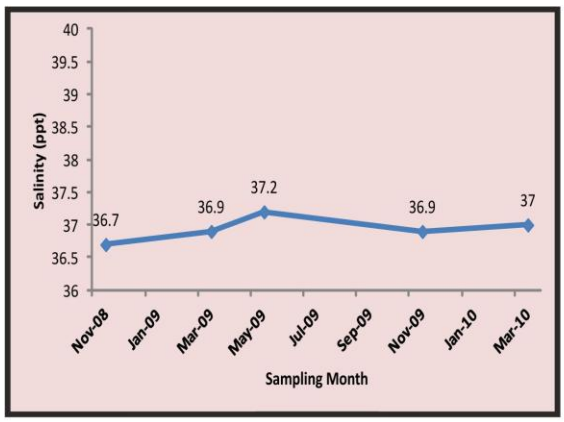
Goose



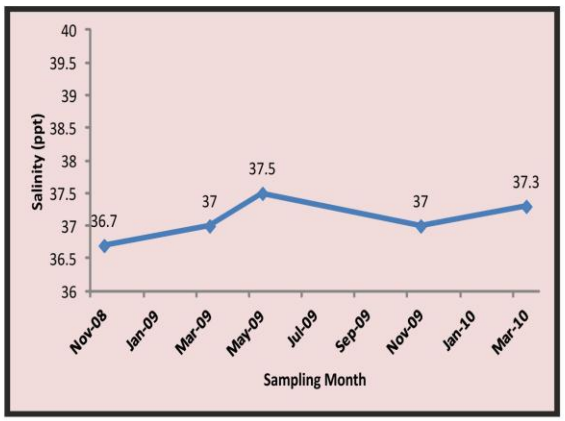
Narara



Kalubhar

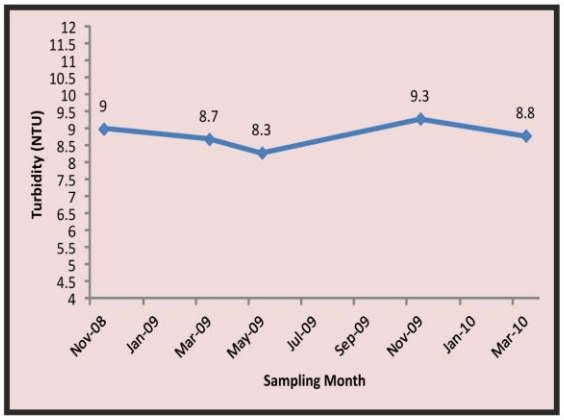


Poshitra

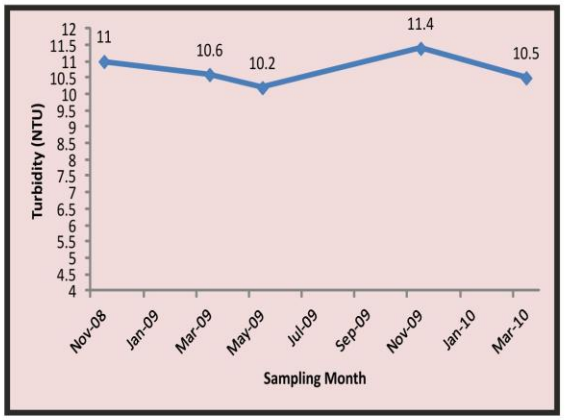


Asabapir

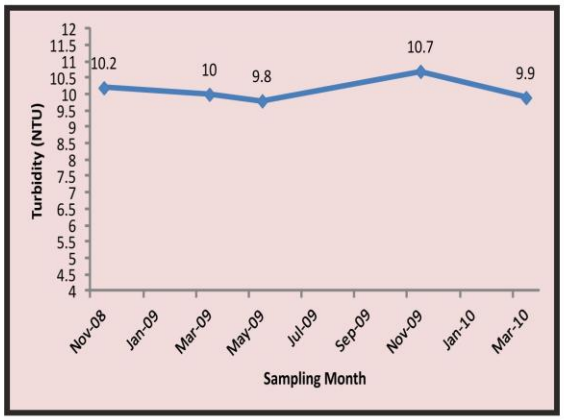
Plate 7.5. Water Turbidity (NTU) at Study Locations



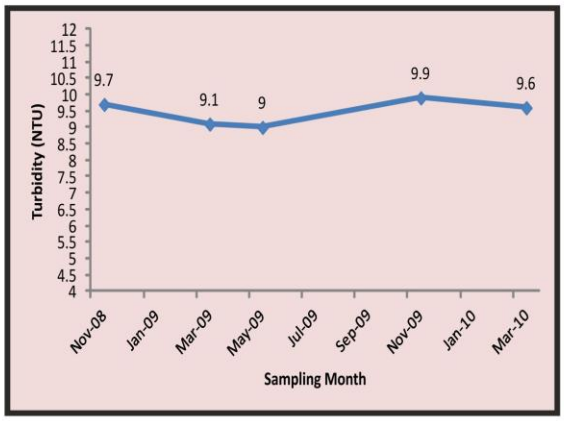
Pirotan



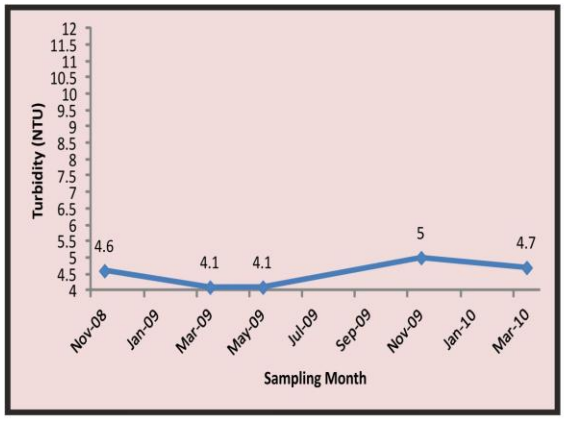
Goose



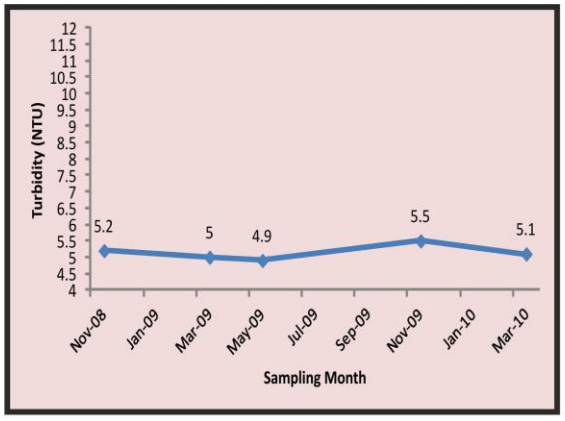
Narara



Kalubhar



Poshitra



Asabapir

Summary

Coral reefs are the most fragile ecosystems of the oceans. Increasing human population and anthropogenic pressures have started severely affecting coral distribution and the biodiversity (West and Salm, 2003). Various activities such as fishing gear operations, anchoring of boats, collecting corals for ornamental purposes, algal collection, shell (molluscs) collection, illegal quarrying of corals, promotion of tourism and activities like mariculture adds to the complexity for the management of coral reef ecosystems in India (Ramaiyan *et al.*, 1995).

In India, Gulf of Kachchh, the largest coastal habitat in the West coast of India in the state of Gujarat (20° 15' to 23° 35' N and 60° 05' to 70° 22' E) encompassing over 1000 km long shoreline (including islands) is covering an area of 7350 sq.km with coral reefs fringed on its southern shore.

Industrial and other developments along this gulf have accelerated in this area in recent years with the establishment of two oil refineries. In addition, the ports at Okha, Kandla, Navlakhi, Mundra and Jakhau handle a variety of cargo. All these developments are responsible for considerable ship traffic in the Gulf. Seventy per cent of India's total crude import is expected to take place through the Gulf of Kachchh. Other major industrial developments around the gulf include a soda ash industry at Mithapur, a cement plant, a thermal power plant and a fertilizer factory at Sikka and a cement complex at Mundra. Many of these industries make use of the gulf either directly or indirectly, may be to draw seawater for cooling or to release wastewater including the return coolant and export/import of materials. Several medium and small-scale industries and saltpans make use of the Gulf in a variety of ways.

Nevertheless, for the status of coral reefs of Gulf of Kachchh, with reference to various hard coral species with its distribution, live coral cover, the water quality, and the status of any associated fauna, no significant current publications are available. The opisthobranch fauna of the GoK is least explored group amongst other associates. They act as indicators of reef health; hence a study was carried out in the GoK with following objectives:

- To know the species composition of corals in identified reef as well as over all species composition in the Marine National Park and Sanctuary - Gulf of Kachchh.
- To assess environmental parameters with reference to live coral cover.
- To know the other associated fauna of the reef
- To assess the health of the reef

Total 38 species of corals belonging to 20 genera were recorded during present study from six study locations, with maximum richness at Asaba Pir with 28 species followed by Poshitra with 26 species. The lowest species richness was at Goose where only 18 species were recorded. The generalist species of all these reefs were mainly *Favia favus, Favia speciosa* and *Porites lutea*, occurring at all six reefs with high relative frequency. Though *Turbinaria peltata* and *Turbinaria reniformes* are the VULNURABLE (IUCN 2010) species, they were recorded from Poshitra and Asaba Pir with higher frequency of occurrence. *T. peltata* was the most frequently occurring species at Poshitra with relative frequency of 29%. Of the eight species categorized as NEAR THREATENED species (IUCN 2010) *viz. Acanthastrea hillae, Favites complanata, Goniopora minor, Pseudosiderastrea tayami, Montipora foliosa, Favites bastae, Montipora venosa* and *Platygyra lamaelinna*, in the present study, first four were found to

be well distributed on GoK reefs, while the fifth species *M. foliosa* though not widely distributed was the most common species at Asaba Pir.

The moderate distribution of remaining two species (at 3 to 4 locations) but with low frequency of occurrence indicate that the species considered as near threatened are either thriving well or trying to sustain themselves in GoK.

The average live coral cover of the six locations in the gulf is 22%, with maximum 41.6 % at Poshitra followed by 36% at Asaba Pir. Lowest coral cover was recorded at Narara with 3.51% followed by Pirotan 14.3% cover. This live coral cover can be considered low, compared to the other reef areas of India. A noticeable trend in live coral cover, frequency and species richness of corals was observed in the present study. While moving from east to west in the gulf these parameters of corals showed increasing trend. Pirotan, Goose, Narara and Kalubhar have significantly low coral coverage and poor richness compared to Poshitra and Asaba Pir, situated on the western extremes of the gulf.

For the reef associated fauna only Opisthobranchs were analysed. Total opisthobranch species richness was 43, with maximum at Asaba Pir with 27 species followed by Poshitra with 26 species. Lowest opisthobranch species richness was recorded at Narara (11 species). 22 species were first record to the country. *Elysia tomentosa* was abundant throughout all the reefs and can be considered as a generalist species for the reefs of GoK. Endemic *Sakuraeolis gujaratika* was also recorded from Poshitra during the current study. Maximum density of opisthobranchs was at Poshitra with 97 / 100 m^2. The lowest was at Kalubhar with 28 / 100m^2. The species richness of opisthobranchs were divided into four major groups *viz*. Elysids, dorids, Aeolids and remaining other species. Elysids feed on vegetation *i.e.* algae while dorids mainly feed on sponges and tunicates, whereas, the Aeolids feed upon stinging hydroids. Based on the IVI value of the species, the dorids were most abundant at Kalubhar followed by Goose 88.5 and Narara 88.3.

Elysids were dominant at Pirotan with 40.8 IVI followed by Kalubhar 39.9 IVI value. The density and diversity of opisthobranchs showed similar trend to that of the corals i.e. low density and diversity in the eastern and central reefs and high density and diversity in the western reefs. In other words it can be said that the opisthobranch fauna showed significant association with the coral diversity and abundance.

To study the water quality five parameters were selected *viz*. Water temperature, pH, Salinity, DO and Turbidity. All the parameters of the marine water of GoK, were well in range, with the signs of degradation evident in the central and eastern gulf through remarkable low DO and pH, high temperature and turbidity and high salinity fluctuations compared to the reefs of the western parts of GoK. These water qualities also give justification to the assumption that the reefs of central and eastern parts of GoK are under heavy pressure and facing severe degradation.

Based on the above mentioned three components, the results revealed that the reefs of central and eastern GoK *viz.* Narara, Goose, Kalubhar and Pirotan are facing severe degradation, which was evident in the past also, before the area was declared as MNP & S. Healthy coral reefs with good density and diversity of corals and other associated fauna at the western parts of GoK indicated low anthropogenic pressure. At this point, it can be suggested that there is an utmost need of restoration of coral reef habitats in the eastern and central reefs of GoK. Whereas for the reefs, located on the western parts of the southern GoK, conservation efforts such as intensive protection and awareness campaigns can help for the better future of the reefs as these reefs face less industrial pressure.

GENERAL CONSIDERATION

Conservation and management practices heavily depend on the scientific data collected through scientific methods, especially for the protected areas. Studies of coral reefs, with reference to its live coral cover, abundance of the coral species, density of associated fauna, reef specific water quality, *etc.*, indicates the status of health of reef's and provide the estimation on reef resilience. These estimations help the managers to plan and act according to the inferences made through such scientific studies. The MNP & S of the Gulf of Kachchh in Gujarat having coral reefs in parts have been neglected for long. Though considered as one of the four major coral reefs of India, except for some of the taxonomic studies, there is no recent data available on the coral reefs of Gujarat. An effort was made to study all the three parameters *i.e.* coral community along with its live cover, associated diversity and the surrounding water quality from six representative sites of the MNP & S.

From the six representative locations of MNP & S the average live coral cover ranged from minimum 3.51% at Narara to maximum 41.6% at Poshitra. In the present study the central gulf locations *i.e.* Narara has shown maximum degradation of live corals in both upper and lower strata, followed by Goose and Pirotan in the eastern gulf and Kalubhar in the central gulf. The reefs of the western gulf are having relatively very good coral assemblages. Similarly for the associated fauna, the density and diversity of opisthobranch fauna was considerably high in the western gulf locations, corresponding to the live coral coverage of the respective reefs. This is also correlated to the availability of food source for these groups of animals.

Though, all the parameters of the marine water of GoK, were well in range, which should ultimately favour the growth of coral reef ecosystem, the signs of degradation were

evident in the central and eastern gulf through remarkable low DO and pH, high temperature and turbidity and high salinity fluctuations compared to the reefs of the western parts of GoK. These water qualities also give justification to the assumption that the reefs of central and eastern parts of GoK are under heavy pressure and facing severe degradation.

In the past, these reefs witnessed dredging of sand and other calcium resources to be intensive in the eastern and central parts of the southern GoK whereas, the western parts were relatively less disturbed. However, to restrict this calcium exploitation from the area the state government declared the area as MNP & S in 1982. However the early 90s industrial development in the south eastern parts of GoK gave a very small time lag to this coral ecosystem to rejuvenate. With the growth rate of 2 mm /year, it is very difficult for the coral reefs to recover within the time span of 10 years. In recent times also, maximum industrial pressure is on the central and eastern parts of the gulf. The list of probable threats in the GoK can be assessed from the following table

Table: Analysis of Probable Threats and their impact on study locations

Sr. No.	Probable Threats	Pirotan	Goose	Narara	Kalubhar	Poshitra	Asabapir
1	Rozy Port	+	-	-	-	-	-
2	Reliance Jetty	+	+	+	+	-	-
3	Reliance Industry	+	+	-	-	-	-
4	GSFC Jetty	-	+	+	-	-	-
5	GSFC Industry	-	+	-	-	-	-
6	Birla Cement	-	+	-	-	-	-
7	Sikka Jetty (Birla cement + GSECL coal)	-	+	+	-	-	-
8	GSECL	-	+	+	-	-	-
9	IOCL Pipeline	-	-	+	+	-	-
10	TCL	-	-	-	-	+	+
11	Okha port	-	-	-	-	+	-
12	Tourism & Direct human damage	+	+	+	+	+	+
13	Past exploitation history	+	+	+	+	+	-
14	Pipeline laying for crude	-	-	+	-	-	-

	transport						
15	ESSAR Oil	-	-	+	+	-	-
16	ESSAR Jetty	-	-	+	+	-	-
17	Run off / Sedimentation	+	+	+	+	+	+
	Total	6	10	11	7	5	4

Excluding the natural threats like cyclones, Tsunami, elevated sea surface temperatures, maximum number of anthropogenic threats *i.e.* 11 manmade threats are faced by Narara reef followed by at Goose. The major threat to these reefs is the sedimentation load. Most of the above mentioned activities have contributed in increase of sedimentation load to the coral reefs as well as pollution, they are considered as threats. Heavy sedimentation is occurring naturally through Indus delta. However due to constructions of dams, this influx is predicted to be reduced. This natural Indus flow has created great damage to the coral reefs of the GoK.

In addition further for various industries major cargo transportation is through the waters of GoK, and large vessels are the cargo carriers of these industries. The maximum depth of gulf is 60 meter and hence to maintain the vessel traffic in the navigational channels in the southern gulf, the industries are carrying out continuous dredging. Such industries and their jetties are situated near the coral reefs of the GoK, dredging and its disposal add to the natural sedimentation, leading to the turbid waters. The most important part of the coral physiology is the photosynthesis taking place in the polyp tissue, for which the coral requires sunlight. Due to the turbidity, the corals cannot photosynthesize actively and can die if the conditions are prolonged. Above all, the settlement of sediments on coral colonies also hinder the coral calcification (growth) rate, alteration of growth forms and various diseases, which can ultimately lead to the death of corals and coral reefs.

These reefs under severe pressure due to all the above mentioned reasons are located from Pirotan (in the east) to Kalubhar (in the central) GoK. Considering the slow coral growth, if such dredging and other industrial pressure continues for a longer duration, the corals will become restricted only to some patches of western gulf. The results of the current study clearly indicate heavy degradation in the central and eastern parts of the GoK with reference to live coral cover and coral species richness, which points out towards the past exploitation of the reefs of eastern and central gulf area and current industrialization, which is also building at rapid pace in the eastern and central GoK.

All the three parameters studied showed similar results, which can be considered as, impact of anthropogenic pressure resulting into poor water quality leading to degradation of reefs in the central parts of GoK, moderate degradation in the eastern reefs, whereas presence of considerably healthy reefs still surviving or trying to survive in the western gulf, which is also evident through the presence of various associated fauna.

For the conservation, reefs of the GoK can be divided in two parts

1. Reefs for restoration (from Pirotan to Kalubhar) Eastren and Central gulf
2. Reefs for conservation (Dhani to Chandri) Western gulf

1. **Reefs for restoration:** Reefs of eastern and central gulf should be restored through transplantation of coral species in this area. Well defined feasibility studies should be planned for finding out the proper recipient sites and suitable coral species for the coral transplantation.
2. **Reefs for conservation:** The reefs of western GoK can be considered for conservation as there is low industrial pressure in the area. Proper monitoring, education for protecting environment and other conservation and protection activities can be done at these reefs. There is also a need for the documentation of major fauna and flora of these reefs.

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